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Risø National Laboratory, DK-4000 Roskilde, Denmark

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ENVIRONMENTAL RADIOACTIVITY IN DENMARK IN 1980

A. Aarkrog, L. Bøtter-Jensen, H. Dahlgaard, Heinz Hansen, J. Lippert, S.P. Nielsen and Karen Nilsson

Abstract. Strontium-90 was determined in samples from all over the country of precipitation, ground water, drinking water, sea water, dried milk, grain, bread, potatoes, vegetables, fruit, total diet, and human bone. Furthermore, ^{90}Sr was determined in local samples of air, rain water, soil, sediments, grass, sea plants, fish and meat. Cesium-137 was determined in air, precipitation, sea water, lake water, sediments, milk, grain products, potatoes, vegetables, fruit, total diet, sea plants, fish, and meat. Estimates of the mean contents of radiostrontium and radiocesium in the human diet in Denmark during 1980 are given. Tritium was determined in precipitation, fresh water and sea water. Plutonium and Americium were measured in sea water sediments, sea plants and mussels. The γ-background was measured regularly by TLD, ionization chamber and on site γ-spectroscopy at locations around Risø, at ten of the State experimental farms along the coasts of the Great Belt and around Gyllingnæs. The marine environments at Barsebäck and Ringhals were monitored for ^{137}Cs and corrosion products (^{58}Co, ^{60}Co, ^{65}Zn, ^{54}Mn). Finally the report includes routine surveys of environmental samples from the Risø area.

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CONTENTS

ABBREVIATIONS AND UNITS

J: joule: the unit of energy; 1 J = 1 Nm (= 0.239 cal)
Gy: gray: the unit of absorbed dose = 1 J kg^{-1} (= 100 rad)
Sv: sievert: the unit of dose equivalent = 1 J kg^{-1} (= 100 rem)
Bq: becquerel: the unit of radioactivity = 1 s^{-1} (= 27 pCi)

cal: calorie = 4.186 J
rad: 0.01 Gy
rem: 0.01 Sv
Ci: curie: $3.7 \cdot 10^{10}$ Bq (= $2.22 \cdot 10^{12}$ dpm)

T: tera: 10^{12}
G: giga: 10^{9}
M: mega: 10^{6}
m: milli: 10^{-3}
µ: mikro: 10^{-6}
n: nano: 10^{-9}
p: pico: 10^{-12}
f: femto: 10^{-15}
a: atto: 10^{-18}

cap: caput: (per individual)
TNT: trinitrotoluol; 1 Mt TNT: nuclear explosives equivalent to 10^{9} kg TNT.

cpm: counts per minute
dpm: disintegrations per minute
OR: observed ratio
CF: concentration factor
FP: fission products
µR: micro-roentgen, 10^{-6} roentgen
S.U.: pCi ^{90}Sr (g Ca)$^{-1}$
O.R.: observed ratio
M.U.: pCi ^{137}Cs (g K)$^{-1}$

V: vertebrae

m: male

f: female

nSr: natural (stable) Sr

eqv. mg KCl: equivalents mg KCl: activity as from 1 mg KCl (~ 0.88 dpm)

S.D.: standard deviation: $\sqrt{\frac{\Sigma(\bar{x}-x_i)^2}{(n-1)}}$

S.E.: standard error: $\sqrt{\frac{\Sigma(\bar{x}-x_i)^2}{n(n-1)}}$

U.C.L.: upper control level

L.C.L.: lower control level

S.S.D.: sum of squares of deviation: $\Sigma(\bar{x}-x_i)^2$

f: degrees of freedom

s^2: variance

v^2: ratio between the variance in question and the residual variance

P: probability fractile of the distribution in question

η: coefficient of variation, relative standard deviation

ANOVA: analysis of variance

A: relative standard deviation 20-33%

B: relative standard deviation >33%, such results are not considered significantly different from zero activity

B.D.L.: below detection limit

In the significance test the following symbols were used:

* : probably significant (P > 95%)

** : significant (P > 99%)

***: highly significant (P > 99.9%)

1. INTRODUCTION

1.1.

The present report is the twenty-fourth of a series of periodic reports (cf. ref. 1) dealing with measurements of radioactivity in Denmark. The organization of the material in the present report corresponds to that of last years report. After the introduction and a chapter on organization and facilities there follows a chapter on environmental monitoring around nuclear facilities (Risø, Barsebäck and Ringhals). Chapter four deals with fallout nuclides in the abiotic environment, i.e. air, water and soil. Chapters five and six comprise fallout nuclides in the human diet and human tissues, respectively. Chapter seven is devoted to environmental tritium studies. Plutonium and Americium in environmental samples are treated in chapter eight, and external radiation in chapter nine. The names of the authors of each chapter appear at its head.

The Becquerel has now replaced the Curie, however, in tables (mean values) and figures the Curie is shown for comparison. In the figures we have used the right-hand ordinate for Curie.

1.2.

The methods of radiochemical analysis[2-4] and the statistical treatment of the results[12] are still based on the principles established in previous reports[1].

1.3.

The environmental monitoring programme for Risø National Laboratory has been revised. Total β-measurements are only performed on waste water. The detailed tables of the programme appears in the two semiannual reports: Radioactivity in the Risø district January-June 1980 and July-December 1980.

1.4.

The report contains no information on sample collection and analysis except in cases where these procedures have been altered.

1.5.

In 1980 the personnel of the Environmental Control Section of the Health Physics Department consisted of two chemists, one biologist, eight laboratory technicians, two sample collectors, and two laboratory assistants. The Section for Electronics Development continued to give assistance with the maintenance of counting equipment, with the interpretation of γ-spectra and with data treatment. The programme (cf. 2) used in the calculations of ^{90}Sr and the γ-analysis, as well as the programme for data treatment, were developed by this Section.

1.6.

The composition of the average Danish diet used in this report is identical with that proposed in 1962 by Professor E. Hoff-Jørgensen, Ph.D.

2. FACILITIES[1,6,7,8]

By J. Lippert

2.1. Detectors

The activity of the samples is measured as follows:

Alpha (^{239}Pu, ^{241}Am): 16 solid-state surface barrier detectors connected to four multichannel analyzers (64 channels per detector) and another two for total alpha counting.

Beta (^{90}Y mainly): Six "multidetector"-systems each containing 5 sample counters and a common anticoincidence shield are now put into regular use. This type of detector has replaced the mechanical sample changers previously used.

Gamma (natural and fallout isotopes): 4 Ge(Li) detectors in 10 cm lead shields and connected to a 8192-channel analyzer with four-input facility. One further Ge(Li) detector mounted on a tripod and a 4096-channel analyzer are used for field measurements, and a 8" × 4" NaI(Tl) in an underground shielded room is used for whole-body counting. The Ge(Li) detectors have an efficiency of $\geq$ 20% (relative to 3" × 3" NaI(Tl)).

2.2. Data treatment

Measured spectra are transferred to a Burroughs B6700 computer for evaluation.

A program system STATDATA[16] is developed for registration and treatment of environmental measurements including multichannel analyzer spectra. To date, approximately 50 000 sets of results have been registered covering the period from 1957.

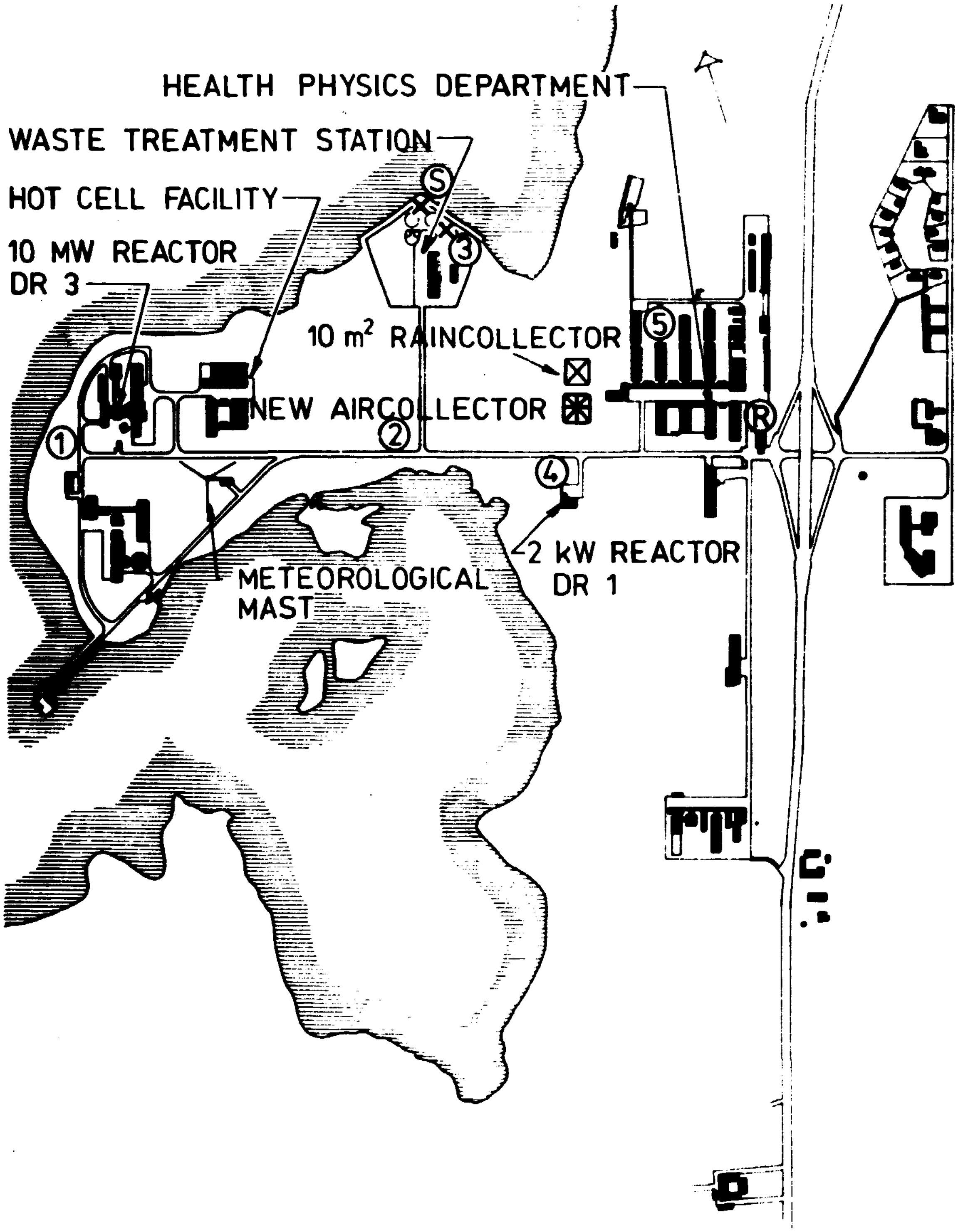

Fig. 3.1.1. Sampling locations at Risø National Laboratory. 1-5: locations for rain bottles (0.03 m^2 each), ion-exchange columns (0.06 m^2 each) and grass samples. S: waste water and grass. R: 1 m^2 daily rain collector. ☒ : 10 m^2 monthly ion-exchange rain collector. ⊡ : new air collector.

3. ENVIRONMENTAL MONITORING AT RISØ, BARSEBÄCK AND RINGHALS IN 1980

by H. Dahlgaard

3.1. Gross β-activity in fresh water from Risø

Fig. 3.1.2 shows the control chart for S (cf. fig. 3.1.1). The yearly means for S in 1980 was 55 eqv. mg KCl l^{-1} (1979: 45). Fig. 3.1.3 shows the activity in waste water.

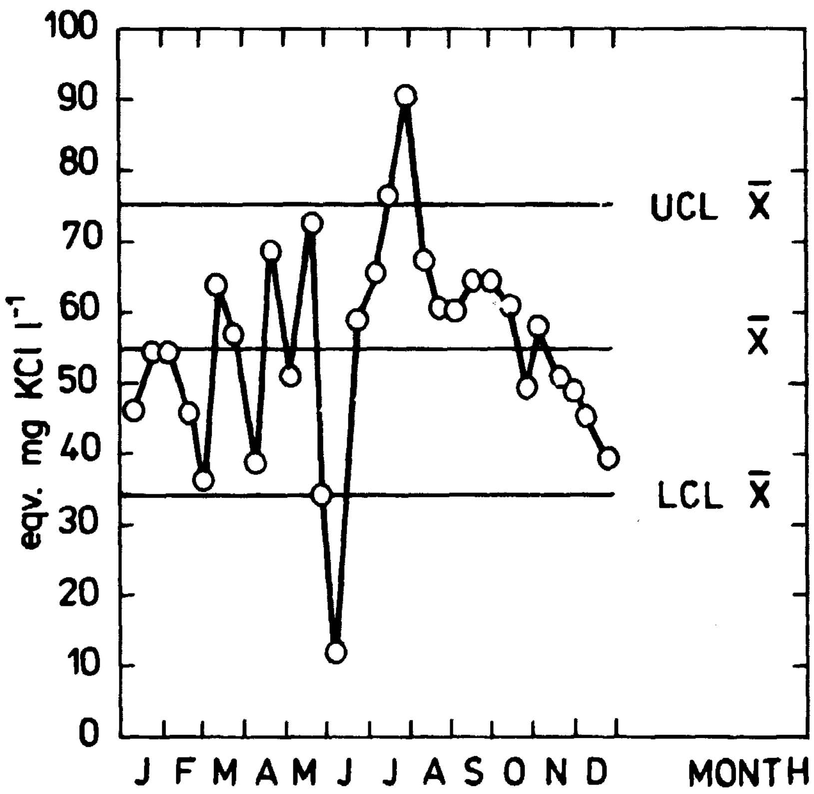

Fig. 3.1.2. Control chart for waste water (S) 1980.

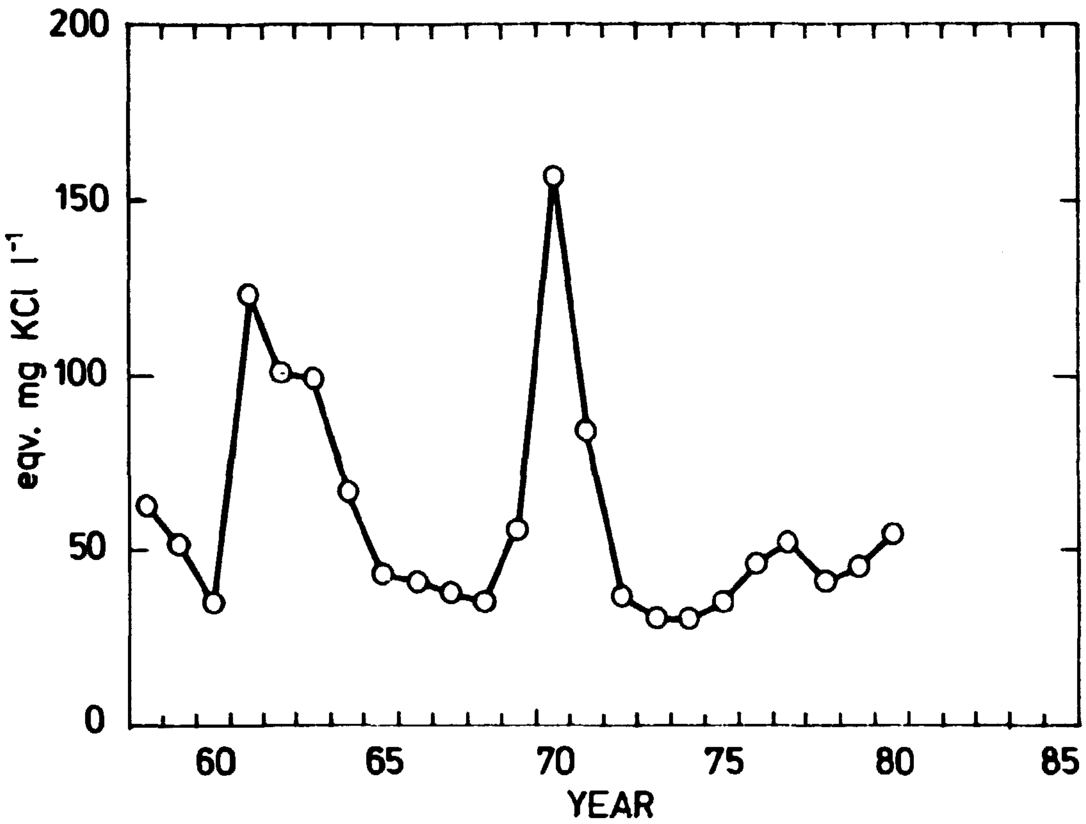

Fig. 3.1.3. Annual total-β mean levels in waste water collected at Risø 1958-1980.

3.2. Marine environmental monitoring at Barsebäck and Ringhals

The radiological monitoring of the marine environment around the two nuclear power plants at Barsebäck and Ringhals in Sweden[1)] was continued in 1980.

Figures 3.2.1.1, 3.2.1.2, and 3.2.1.3 show the sampling locations.

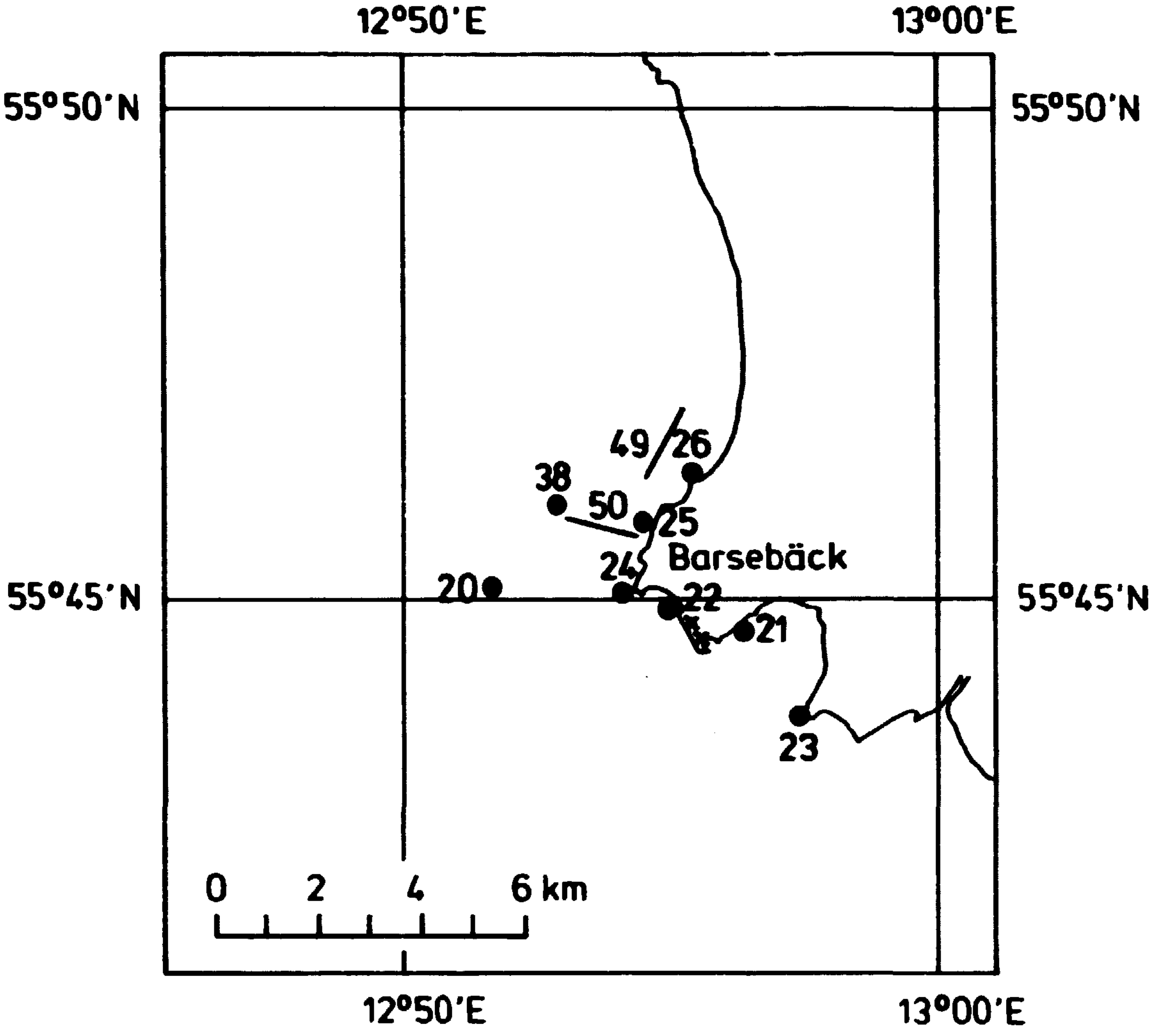

Fig. 3.2.1.1. Sampling locations at Barsebäck. 49 and 50 indicate fishing tracks.

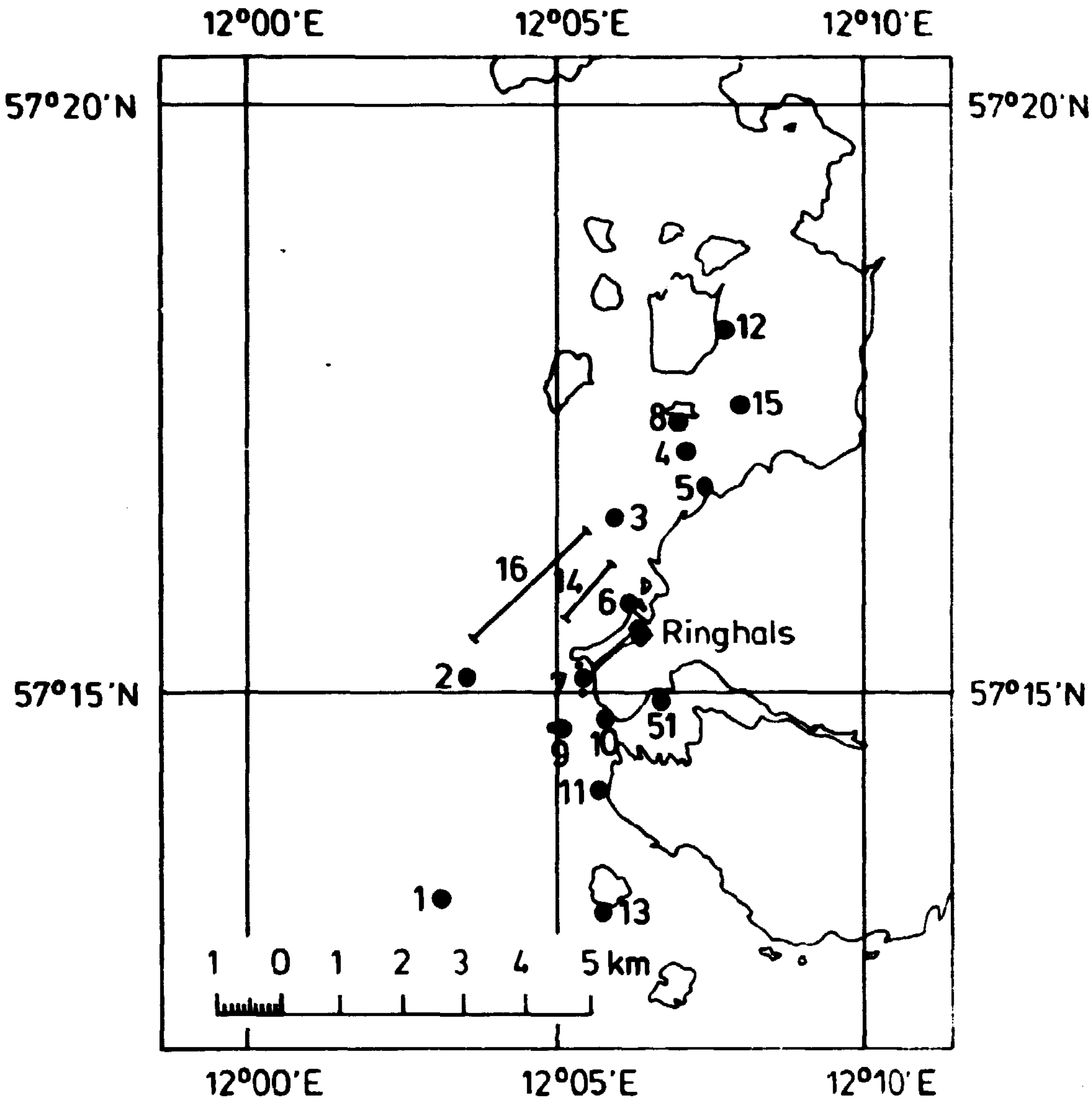

Fig. 3.2.1.2. Sampling locations at Ringhals. 14 and 16 indicate fishing tracks.

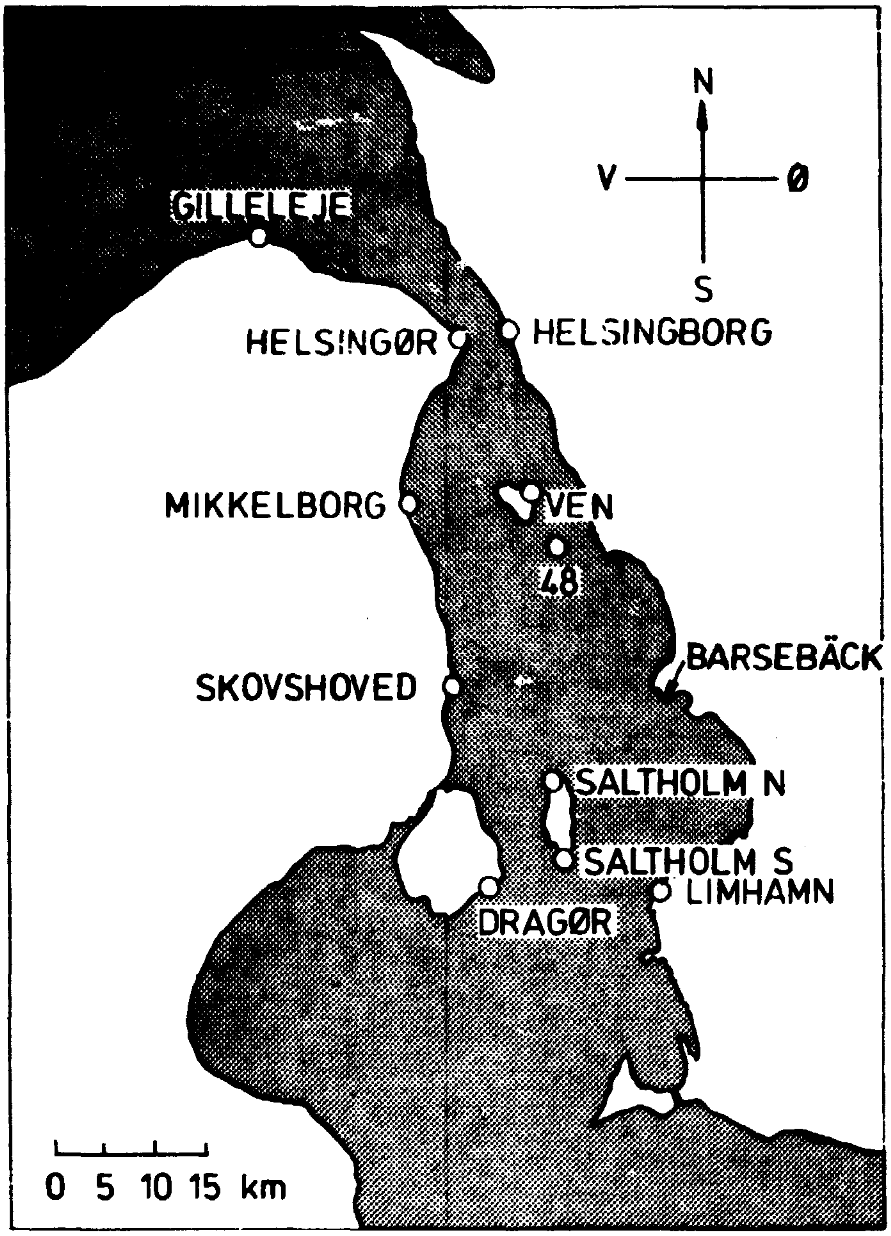

Fig. 3.2.1.3. Sampling locations in the Sound.

This programme is sponsored by the Nordic Liaison Committee for Atomic Energy (Nordisk kontaktorgan for atomenergi) as part of a co-operative activity together with the Department of Radiation Physics, University of Lund, Sweden.

3.2.1. γ-emitting radionuclides in brown algae

Tables 3.2.1.1, 3.2.1.2, and 3.2.1.3 show the radionuclide concentrations found by γ-spectrometric analysis in brown algae sampled near Barsebäck and Ringhals in 1980. Table 3.2.1.4 presents results from the Sound (Øresund) further away from Barsebäck.

As noted in the preceding reports[1] the concentration of the reactor-produced nuclides, ^{60}Co, ^{58}Co, ^{54}Mn, ^{65}Zn, and ^{110m}Ag,

Table 3.2.1.1. Gamma-emitting radionuclides in Fucus vesiculosus (Fu.ve.), Fucus serratus (Fu.se.) and Zostera marina (Zo.ma.) collected at Barsebäck in 1980 (Unit: Bq kg^{-1} fresh weight)

Date of sampling	1 April		12 August				
Station No.**	24	23*	24	24	26	23*	23*
Weight fresh/dry	5.35	6.58	3.93	3.75	4.54	3.60	7.57
Species	Fu.ve.	Fu.ve.	Fu.ve.	Fu.se.	Fu.ve.	Fu.ve.	Zo.ma.
Distance from outlet in km	1.4	2.8	1.4	1.4	4.0	2.8	2.8
^{60}Co	330	7.6	400	450	49	18.5	13.4
^{58}Co	14.2	0.2 A	65	73	7.5	2.2	2.5
^{54}Mn	9.2	0.46	17.0	17.4	2.9	0.79	0.6 A
^{65}Zn	56	1.37	52	59	5.2	2.1	2.6
^{110m}Ag	0.8 A						
^{137}Cs	2.6	1.97	3.5	3.6	3.2	3.8	
^{131}I	1.3 A	0.69					

* Locations south of the outlet; the other locations were situated north of the outlet.

**Cf. Fig. 3.2.1.

Table 3.2.1.2. Gamma-emitting radionuclides in *Fucus vesiculosus* (Fu.ve.), *Ascophyllum nodosum* (As.no.) and *Fucus serratus* (Fu.se.) collected at Ringhals July 15 and 16, 1980. (Unit: Bq kg^{-1} fresh weight)

Station No.**	7	7	6	5	8	8	8	12	12	9*	11*	13*
Weight fresh/dry	4.36	3.51	4.42	4.70	3.82	3.88	3.95	4.43	3.96	4.15	4.81	4.91
Species	Fu.ve.	As.no.	Fu.ve.	Fu.ve.	Fu.ve.	As.no.	Fu.se.	Fu.ve.	Fu.se.	Fu.se.	Fu.ve.	Fu.ve.
Distance from outlet in km	0.2	0.2	1.9	4.1	4.8	4.8	4.8	6.3	6.3	1.1	1.9	4.1
^{60}Co	52	51	8.0	4.6	3.9	3.6	5.3	4.2	6.7	23	8.6	1.46
^{58}Co	22	14.7	3.7	2.2	2.6	1.2 A	2.6	2.0	3.8	13.0	3.7	0.6 A
^{54}Mn	4.4	1.6 A	0.5 A		0.3 A		0.3 B		0.4 A	1.0 A	0.5 A	
^{65}Zn	122	147	11.2	7.0	5.4	5.9	9.6	[illegible]	5.4	63	41	4.5
^{137}Cs	3.9	3.7	2.7	2.3	3.3	2.8	3.5	4.3	4.1	3.1	2.7	2.5
^{110m}Ag	3.2	4.5	0.4 A							1.46	1.14	
^{134}Cs	0.5 A	0.2 A						0.3 A		0.4 A	0.3 A	

* Locations south of the outlet; the other locations were situated north of the outlet.

**Cf. Fig. 3.2.2.

Table 3.2.1.3. Gamma-emitting radionuclides in *Fucus vesiculosus* (Fu.ve.), *Fucus serratus* (Fu.se.) and epiphytic green algae collected at Ringhals October 5, 1980. (Unit: Bq kg^{-1} fresh weight)

Station No.**	7	7	6	5	8	12	9*	11*	13*
Weight fresh/dry	3.46	8.13	3.45	4.35	3.65	3.76	3.97	3.67	3.70
Species	Fu.se.	epiphyt	Fu.ve.	Fu.ve.	Fu.ve.	Fu.se.	Fu.ve.	Fu.se.	Fu.ve.
Distance from outlet in km	0.2	0.2	1.9	4.1	4.8	6.3	1.1	1.9	4.1
^{60}Co	98	18.8	14.7	4.6	4.4	6.1	15.7	25	4.0
^{58}Co	22	4.3	2.7	1.15	0.93	1.25	4.1	5.0	0.77
^{54}Mn	3.1	1.6 A	0.99	0.3 B	0.4 A	0.4 A	0.71	0.8 A	0.3 A
^{65}Zn	360	171	27	15.7	18.2	9.3	60	134	18.6
^{137}Cs	4.7	3.0	4.5	2.6	3.5	4.0	2.6	3.4	3.5
^{110m}Ag	11.0	25	1.01	0.61	0.5 A		5.8	4.8	1.17

* Locations south of the outlet; the other locations were situated north of the outlet.

**Cf. Fig. 3.2.2.

Table 3.2.1.4. Gamma-emitting radionuclides in Fucus vesiculosus (Fu.ve.), Fucus serratus (Fu.se.) and Ascophyllum nodosum (As.no.) collected in the Sound in 1980. (Unit: Bq kg^{-1} fresh weight)

Date of sampling	? April	? April	? April	? April	13 August	13 August	13 August	13 August	8 August	16 August	19 August	22 December
Location*	Limhamn	[illegible]	Helsingborg	Helsingør N	Saltholm N	Limhamn	Saltholm S	Saltholm S	Skovshoved	Dragør	Dragør	Skovshoved
Weight fresh/dry	5.5?	5.?0	7.??	6.??	3.83	3.??	4.??	5.97	4.43	4.52	4.5?	4.57
Distance from outlet in km	17.0	30.2	39.0	39.4	13.7	17.0	[illegible]	[illegible]	2?.0	25.7	25.7	29.?
Species	Fu.ve.	Fu.ve.	Fu.ve.	Fu.se.	Fu.ve.	Fu.ve.	Fu.ve.	As.no.	Fu.se.	Fu.ve.	As.no.	Fu.se.
^{60}Co	0.??	0.??	0.53	0.??	?.??	?.??	?.?? A		0.65	?.??		?.??
^{137}Cs	2.?	?.??	1.65	2.?	3.?	3.2	2.6	0.27 A	2.?	2.6	?.??	2.?
^{95}Zr												?.44
^{95}Nb												?.??
^{54}Mn	0.?? A				?.?? A							
^{131}I		?.??	0.2 ?	?.?? A								
^{65}Zn				?.?? A								

*Cf. Fig. 3.2.1.[illegible]

decreases with distance from the outlet in a similar manner.

The decrease in concentration 125 km along the Swedish West Coast north of the Barsebäck outlet has been described by a power function: $A = k\ X^{-1.4\pm0.1}$, where A is the activity concentration in Fucus and X the distance in km[17].

The long-distance data from the Sound (Table 3.2.1.4) indicate that only a minor fraction of the activity reaches the Danish coast, and the main part of the plume from Barsebäck remains near the Swedish west coast.

Expressing the decrease in activity with distance from Ringhals by a power function, $A = kX^{-\beta}$, gives β-values of 0.83 and 0.95 northwards for July and October 1980, respectively. Southwards, the corresponding figures are 1.06 and 0.87. A pooling of the results from 1977-1980 yields β-values of 0.80 ± 0.04 (S.E., n = 7) and 0.95 ± 0.04 (S.E., n = 6) northwards and southwards, respectively.

Table 3.2.1.5 shows a comparison of the 3 fucoids Fucus vesiculosus, Fucus serratus, and Ascophyllum nodosum. Only ^{60}Co results for Fucus vesiculosus and Fucus serratus differ significantly from unity. The ratio: $^{60}Co/^{58}Co$ tends to increase in the order: Fucus vesiculosus < Fucus serratus < Ascophyllum nodosum, meaning that the "integration time" rises in the same

Table 3.2.1.5. Ratios of activity concentrations on fresh weight basis in Fucus vesiculosus (Fu.ve.), Fucus serratus (Fu.se.) and Ascophyllum nodosum (As.no.) collected at Ringhals 1978, 1979 and 1980

Isotope	Fu.ve./Fu.se.		Fu.ve./As.no.	
^{60}Co	0.70±0.07	(n=6)	1.1±0.3	(n=5)
^{58}Co	0.88±0.06	(n=5)	2.9±0.8	(n=5)
^{54}Mn	1.1 ±0.2	(n=3)	2.3	(n=1)
^{65}Zn	0.90±0.20	(n=5)	1.4±0.3	(n=5)
^{110m}Ag	1.0 ±0.2	(n=2)	1.0±0.2	(n=3)
^{137}Cs	1.0 ±0.1	(n=4)	1.1±0.1	(n=2)
^{131}I	1.0	(n=1)	0.8	(n=1)
^{95}Zr	1.1	(n=1)		

The error term was 1 S.E.

manner. This may be explained by differences in the mean age of the various species sampled.

Tables 3.2.1.6-3.2.1.8 report transfer factors calculated as

$$TF = \frac{A_i}{\frac{1}{m}\sum^{m} D_j} , \left(\frac{Bq\ kg^{-1}}{GBq\ month^{-1}}\right)$$

and decay-corrected transfer factors calculated as

$$DTF_m = \frac{A_i}{\sum^{m} D_j e^{-\lambda(i-j)}} , \left(\frac{Bq\ kg^{-1}}{GBq\ (m\ months)^{-1}}\right)$$

where A_i is the activity of the sample collected in month i (Bq kg^{-1} fresh weight), D_j is the discharge during month j (Bq $month^{-1}$), m is the number of months in the calculation, and λ is the radioactive decay constant ($month^{-1}$). Monthly discharges are from Reference 36. In the TF-calculation m is 12 months, whereas in the DTF-calculation m is chosen as the number of months for which DTF-values for ^{60}Co and ^{58}Co are equal. The "integration-time" is defined as this last m-value. If more months than the "integration time" are included in the calculation, DTF for ^{60}Co ($T_{\frac{1}{2}}$ ~ 1922 d) will be smaller than DTF for

Table 3.2.1.6. Transfer factor, TF, without decay-correction. Fucus vesiculosus collected at Barsebäck, location 24, 1.4 km north of the outlet

Isotope	Sampling date	Discharge the preceding 12 months GBq month^{-1}	rel. S.D.%	TF Bq kg^{-1} / GBq month^{-1}
^{60}Co	1/4-80	2.06	49	161
"	12/8-80	2.62	65	155
^{60}Co mean:	1980			158 ± 3
	1979			170 ±41
	1978			122 ±65
	1977			168 ±46
^{58}Co	1/4-80	0.63	92	22.6
"	12/8-80	0.66	103	99.8
^{58}Co mean:	1980			61 ±39
	1979			25.3± 9.5
	1978			68 ±30
	1977			75 ±25
^{54}Mn	1/4-80	0.156	95	58.9
"	12/8-80	0.153	99	111.0
^{54}Mn mean:	1980			85 ±26
	1979			79 ±10
	1978			77 ±27
	1977			133 ±25
^{65}Zn	1/4-80	0.455	65	122
"	12/8-80	0.538	80	96
^{65}Zn mean:	1980			109 ±13
	1979			141 ±40
	1978			132 ±72
	1977			157 ±43
^{110m}Ag	1/4-80	0.064	74	12.9
^{110m}Ag mean:	1980			12.9
	1979			14.3± 2.1
	1978			16.4±11.7
	1977			14.7± 7.5
^{51}Cr mean:	1979			14.8
	1978			1.5
	1977			5.6

The error term was ±1 S.E.

Table 3.2.1.7. Transfer factor, TF, without decay-correction. Brown algae (from Tables 3.2.1.2 and 3.2.1.3) collected at Ringhals, location 6, 1.9 km north of the outlet and location 9, 1.1 km south of the outlet

Isotope	Sampling date	Discharge the preceding 12 months		$TF = \frac{Bq\ kg^{-1}}{GBq\ month^{-1}}$	
		GBq month^{-1}	rel. S.D.%	Location 6	Location 9
^{60}Co	15/7 -80	7.25	70	1.10	3.15
"	5/10-80	7.60	71	1.93	2.07
^{60}Co mean:	1980			1.52±0.42	2.61±0.54
	1979			2.40	2.06±0.38
	1978			1.51±0.31	1.89±0.69
	1977			4.09±0.56	6.90±0.90
^{58}Co	15/7 -80	1.83	95	2.00	7.09
"	5/10-80	1.60	112	1.66	2.54
^{58}Co mean:	1980			1.83±0.17	4.82±2.28
	1979			1.72	2.15±0.99
	1978			0.85±0.38	1.70±0.76
	1977			1.21±0.67	2.50±1.02
^{54}Mn	15/7 -80	0.46	88	1.09	2.14
"	5/10-80	0.45	90	2.21	1.59
^{54}Mn mean:	1980			1.65±0.56	1.86±0.28
	1979			2.06	2.81±0.94
	1978			1.90±0.40	1.92±0.58
	1977			4.70±2.36	3.78±0.52
^{65}Zn	15/7 -80	7.80	172	1.43	8.05
"	5/10-80	3.41	79	7.94	17.5
^{65}Zn mean:	1980			4.68±3.26	12.8±4.7
	1979			7.69	13.0±3.9
	1978			4.54±0.08	10.6±5.1
	1977			12.9±7.9	22.7±10.2
^{110m}Ag	15/7 -80	0.015	130	28.4	100
"	5/10-80	0.078	250	13.0	75
^{110m}Ag mean:	1980			20.7±7.7	88 ±12
	1979			6.35	9.2±2.3
	1978			4.80±0.22	5.01
	1977			45.8	49.0

The error term was ±1 S.E.

the relatively short-lived ^{58}Co ($T_{\frac{1}{2}}$ ~ 71.3 d), as ^{60}Co-releases not included in the sample are included in the calculation, whereas the corresponding ^{58}Co discharges have decayed. The calculation of the "integration time" by DTF-values is made on the assumption that the algae cannot distinguish between the two isotopes, i.e. they are assumed to be in the same physico-chemical state.

Table 3.2.1.8. Decay-corrected transfer factors, DTF. Fucus vesiculosus collected at Barsebäck, location 24, 1.4 km north of the outlet. (Unit: Bq (m months) kg^{-1} GBq^{-1})

Date of sampling	770615	771022	771206	780417	780615	780908*	781210	790406	790619	800107	800401	800812
m month	7	7	4	8	8	3	10	13	16	16	19	5
^{60}Co	31.5	21.9	23.5	3.33	8.13	24.1	29.9	20.6	7.14	9.20	8.53	28.2
^{58}Co	28.8	21.9	23.7	3.30	7.67	23.3	30.3	20.6	7.08	8.69	9.07	27.3
^{54}Mn	41.8	18.4	22.8	3.22	9.01	16.6	18.4	12.3	7.00	7.88	5.78	29.2
^{65}Zn	34.1	22.6	25.0	5.14	9.36	22.7	46.0	30.9	10.7	13.2	12.7	24.3
^{110m}Ag	2.6	4.2		0.66			3.74	2.53	1.45	1.08	0.96	
^{51}Cr	6.6			0.77				10.6				

*Mean of 2 samples.

Values of the normal transfer factor, TF, and the decay-corrected transfer factor, DTF, from this investigation have been reported and discussed earlier[1,32].

In Tables 3.2.1.6 and 3.2.1.7 normal transfer factors, TF, from Barsebäck and Ringhals from 1980, and mean values from 1977-1980 are reported. These values can be extrapolated to other distances by the power functions mentioned above. As the monthly discharges are very different the TF-values will vary even if the plants accumulate the same fraction of the discharged nuclides throughout the year. Differences in growth and perhaps in temperature also contribute to the variation. The fairly good reproducibility of the TF-value for most nuclides from both Barsebäck and Ringhals is therefore remarkable. These TF-values, calculated on the basis of controlled discharges during several years, can be used to estimate the magnitude of an uncontrolled release of the basis of a few Fucus samples. A bias may occur due to differences in chemical specification. However, this will not be serious as bioindicator data reports the biologically available fraction and thereby the potential transport to man.

A comparison of the TF-values from Barsebäck and Ringhals indicates that even if the values are calculated for the same distance, or transformed to the same distance by the power functions established above, the TF-values for radiocobalt, ^{54}Mn, and ^{65}Zn are much higher in the Barsebäck than in the Ringhals area, whereas the ^{110m}Ag values are of the same order of magnitude. Furthermore, at Barsebäck the TF-values for ^{65}Zn are of the same magnitude as those for ^{60}Co and ^{54}Mn, whereas at Ringhals the ^{65}Zn values are higher than those of ^{60}Co and ^{54}Mn. Thus, it is evident that differences between Barsebäck and Ringhals are not limited to absolute values of the transfer factors (e.g. due to hydrodynamical differences) but extend to ratios between different pairs of radionuclides.

These apparent differences in accumulation of the various nuclides between the two sites could be explained by differences between the environments. For instance, salinity is higher, approx. 20 o/oo, in the Ringhals area, whereas it is lower, averaging approx. 10 o/oo, in the Barsebäck area. However, a more reasonable explanation is that the radionuclides may be discharged in different physico-chemical forms from the two plants due to differences in waste-water treatment.

Decay-corrected transfer factors, calculated for the number of months, m, that make ^{60}Co and ^{58}Co values approximately equal, are reported in Table 3.2.1.8. "m" is denoted the "integration time", which was described previously[1,32]. As the DTF-values are independent of the physical decay of the nuclides, they are supposed to show the transfer of the metals independently of the decay constants. The variation observed for the DTF-values is apparently not correlated to season (cf. Table 3.2.1.8) as previously suggested[1].

3.2.2. γ-emitting radionuclides in benthic invertebrates

In 1980, 2 mussel samples from Barsebäck were analysed (cf. Table 3.2.2.1); of these one (location 26) is comparable with a Fucus sample (cf. Table 3.2.1.1).

Table 3.2.2.1. Gamma-emitting radionuclides in Mytilus edulis collected at Barsebäck in 1980. (Unit: Bq kg^{-1} fresh weight)

	Date	Sampling* location	Depth in m	Weight fresh/dry	^{137}Cs	^{58}Co	^{65}Zn	^{60}Co
Soft part	12/8	26	0.5	21	0.165	0.24	1.34	1.74
Shells	"	"	"	1.15			0.81 A	1.94
Soft part	13/8	49	7	9.7	0.36	0.29 A	2.0	1.70

*Cf. Fig. 3.2.1.1.

In Ringhals, 4 mussel samples were collected at the same sites as brown algae, and activity ratios were calculated as previously[1] (Table 3.2.2.3). The mean values from 1977-1980 indicate that Fucus from Ringhals concentrates the corrosion products to a level approximately 5 times higher than Mytilus on a fresh weight basis. The dose commitment to a hypothetical critical individual consuming 20 kg Mytilus edulis soft parts yearly would be approximately 3 μSv y^{-1} based on the 4 samples. Thus, this extreme approach gives only 0.3% of the yearly background radiation dose.

Table 3.2.2.2. Gamma-emitting radionuclides in benthic animals collected at Ringhals in 1980. (Unit: Bq kg^{-1} fresh weight)

Species	Date	Sampling* location	Weight fresh/dry	Depth in m	^{137}Cs	^{60}Co	^{58}Co	^{65}Zn	^{110m}Ag	^{54}Mn
Mytilus edulis (soft part)	15/7	7	7.2	0.5	0.53	9.1	2.4	90	1.56	0.25 A
" " " "	"	8	7.0	0.2-1.0		2.5		6.8 A		
Cyprina islandica (soft part)	16/7	16	5.2	18	0.94	0.46		0.90	0.12 A	
" " (shells)	"	"	1.06	"	0.60	1.44				
Starfish	20/7	14	3.6	15	1.02	0.55		10.4	0.59 A	0.21 A
Mytilus edulis (soft part)	5/10	7	7.6	0.5	0.38	4.8	0.85	122	3.3	
" " " "	"	12	5.3	"	0.97	0.62		9.2	0.24 B	
Cyprina islandica (soft part)	11/10	16	5.9	18	0.84	0.48		0.51	0.15 A	0.09 A

*Cf. Fig. 3.2.1.2.

Table 3.2.2.3. Activity ratios on fresh weight basis, Mytilus edulis soft part (from Table 3.2.2.2) to Brown algae (from Tables 3.2.1.2 and 3.2.1.3) collected at Ringhals in 1980

Brown algae	Location	Date	^{60}Co	^{58}Co	^{54}Mn	^{65}Zn	^{137}Cs	^{110m}Ag
Fucus vesiculosus	7	15/7	0.18	0.11	0.06	0.74	0.14	0.49
Fucus vesiculosus	8	"	0.64			1.26		
Fucus serratus	7	5/10	0.05	0.04		0.34	0.08	0.30
Fucus serratus	12	"	0.10			0.99	0.24	
Fu.ve. and Fu.se.								
Mean 1977-1980			0.20	0.16	0.07	0.52	0.30	0.30
S.E.			0.05	0.04	0.01	0.11	0.07	0.09
n			12	9	3	10	7	5

3.2.3. γ-emitting radionuclides in fish

Corrosion-product levels in fish caught near Barsebäck and Ringhals are low (Table 3.2.3.1). The dose commitment to a hypothetical critical individual consuming 100 kg fish meat yearly from the vicinity of Ringhals would be approximately 5.5 µSv y^{-1} or 0.5% of the yearly background radiation dose based on the results from Table 3.2.3.1. Of this dose the power plant is responsible for only approximately 0.7 µSv, as the radiocesium originates from Windscale and from fallout.

Table 3.2.3.1. Gamma-emitting radionuclides in fish meat collected at Barsebäck August 13, 1980 and at Ringhals July 20, 1980. (Unit: Bq kg^{-1} fresh weight)

Location	Species	^{137}Cs	^{65}Zn	^{60}Co	^{134}Cs
Barsebäck 50	Flounder	1.71	0.58 A		
Ringhals 14	Sea scorpion	4.1	4.8	0.90 A	
" "	Dab and plaice	3.1	1.35	0.19 A	0.21 A
" "	Catfish	4.5	0.87	0.29	0.21

3.2.4. γ-emitting radionuclides in sea sediments

As previously sediments sampled by the HAPS bottom corer[18)] were sliced in 3-cm thick sections and analysed by γ-spectrometry (cf. Tables 3.2.4.1 and 3.2.4.2). ^{60}Co originating from the power plants was detectable at both sites.

Table 3.2.4.1. Gamma-emitting radionuclides in sediment samples collected at Barsebäck location 38 in 1980

Date	Depth in cm	^{137}Cs		^{60}Co		^{134}Cs	
		Bq kg^{-1}	Bq m^{-2}	Bq kg^{-1}	Bq m^{-2}	Bq kg^{-1}	Bq m^{-2}
8/8	0-3	68	690	14.9	150	1.89	19.2
"	3-6	34	390	1.39	16.3		
"	6-9	6.1	65				
"	9-12	11.4	139				
"	12-15	3.9	50				
"	15-18	2.1	24				
	0-18		1360		166		19.2
20/12	0-3	72	850	20	230	2.0 A	23 A
"	3-6	38	420	3.4	38		
"	6-9	8.1	101				
	0-9		1370		268		23

Table 3.2.4.2. Gamma-emitting radionuclides in sediment samples collected at Ringhals location 2 in 1980

Date	Depth in cm	^{137}Cs		^{60}Co		^{134}Cs		^{125}Sb	
		Bq kg^{-1}	Bq m^{-2}	Bq kg^{-1}	Bq m^{-2}	Bq kg^{-1}	Bq m^{-2}	Bq kg^{-1}	Bq m^{-2}
20/7	0-3	23	480	8.6	181				
"	3-6	11.5	374	1.81	59				
"	6-9	6.3	217						
"	9-12	lost	lost						
"	12-15	1.69	54						
	0-9		1070		240				
11/10	0-3	20	550	27	743	1.0 A	27 A	2.9 A	78 A
"	3-6	11.0	370	2.1	73				
"	6-9	3.8	145						
	0-9		1070		820		27		78

4. FALLOUT NUCLIDES IN THE ABIOTIC ENVIRONMENT

by A. Aarkrog and J. Lippert

4.1. Air

4.1.1. Strontium-90

The mean air activity level for 1980: 9.9 µBq ^{90}Sr m^{-3}, i.e. 0.7 times the 1979 level. The maximum activity in 1980 was measured in May at 17.1 µBq ^{90}Sr m^{-3}.

Table 4.1.1. Strontium-90 in air collected at Risø in 1980. (Unit: µBq m^{-3})

Month	Daily air filters	Weekly air filters
	Paper	Glass
January	6.3	7.8
February	7.5	
March	11.4	
April	10.1	13.6
May	17.1	
June	15.4	
July	13.6	
August	9.6	
16/9-29/9*	5.6	
October*	9.7	
November*	6.1	
December	6.2	
1980	9.9	
1980 fCi m^{-3}	0.27	

*Glass fibre filters

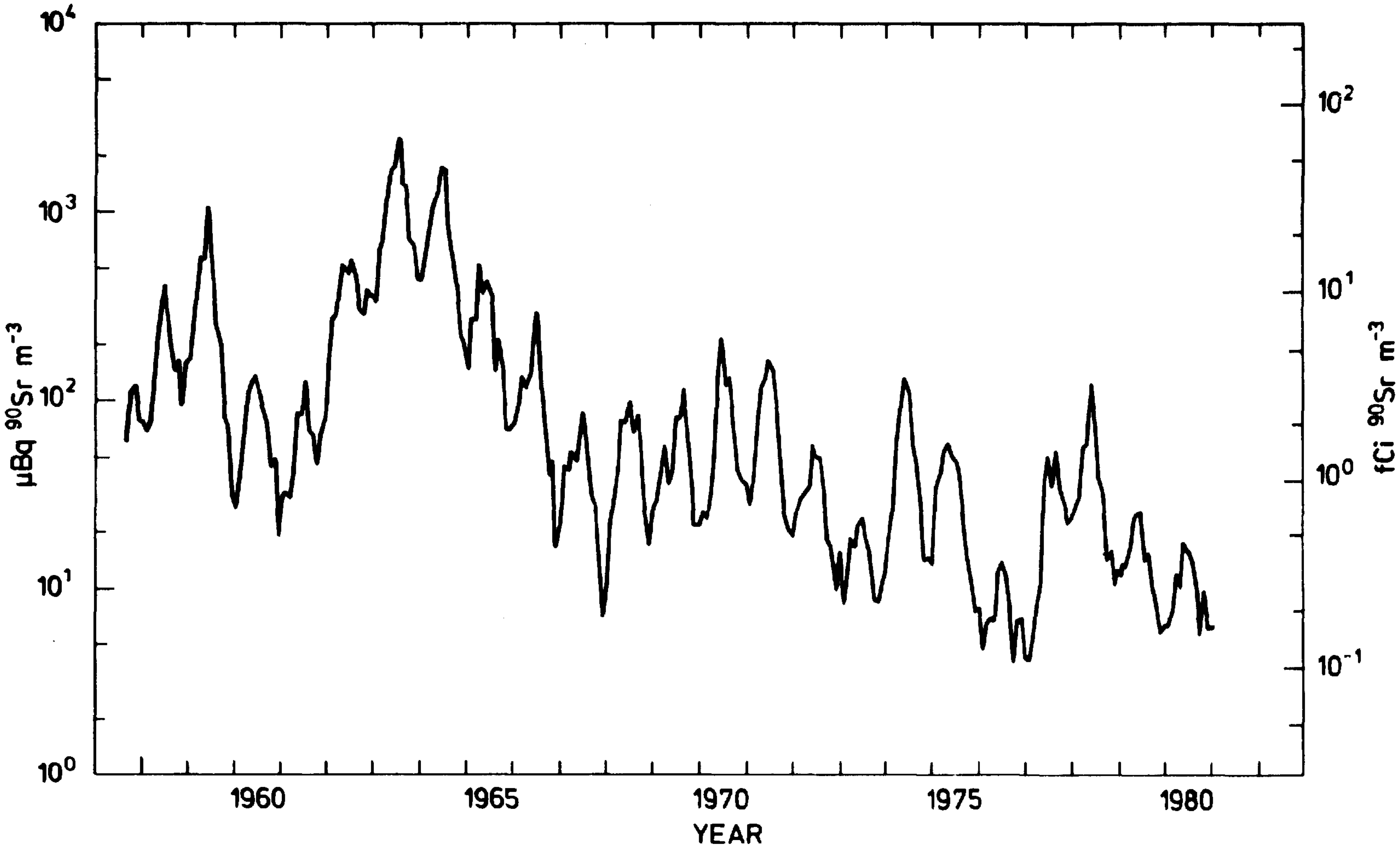

Fig. 4.1.1. Strontium-90 in ground level air at Risø, 1957-1980.

Figure 4.1.1 shows the quarterly levels of ^{90}Sr in air since 1957.

4.1.2. Cesium-137

Air samples were collected weekly by means of a new air sampler installed in 1979 at Risø. The sampler collects the air dust on 6 glassfibre filters each 56 × 48 cm^2. The filters collect approximately 275,000 m^3 in one week. Similar samplers have been operated during 1980 in Bornholm and in Mors (NW-Jutland).

Table 4.1.2.1 shows the monthly ^{137}Cs concentrations in air from the three stations. It is evident that there was no local variation between the three. Hence global air activity in Denmark seems adequately monitored by one sampling station.

Table 4.1.2.1. Cesium-137 in glass-fibre air filters collected once a week at three locations in Denmark in 1980. (Unit: $\mu Bq\ m^{-3}$)

Month	Risø	NW-Jutland	Bornholm
January	5.9±1.2		5.5±0.6
February	5.2±0.6		5.6±0.9
March	11.1±2.3		11.1
April	11.4±2.2		8.7
May	15.6±2.6	17.8±5.0	14.4±0.04
June	16.2±3.4	12.0	14.9
July	13.1±2.1	9.6	13.1
August	9.6±3.5	8.1	10.6
September	4.7±0.6	6.3	5.2
October	2.6±0.3	3.0	3.1
November	3.1±0.7		3.6±0.6
December	5.6±1.0		4.4
1980	8.7		8.4
1980 $fCi\ m^{-3}$	0.24		0.23

The error term is the S.E. of the mean of the activity found in 4 or 5 weekly filters collected during a month. In case of no error term the filters have only been measured monthly.

Strontium-90 analyses of the glassfibre filters from the old air sampler have revealed that the gas meter of the old sampler was inoperative in 1978 and in the first half of 1979. The gas meter underestimated the air volume passing through the filters in this period. The ^{137}Cs results (and results of other γ-emitters in these air filters) from 1978 should be multiplied by 0.54, and from the first half of 1979 by 0.65 (cf. Risø-R-403[1]) p. 38-41 and Risø-R-421[1]) p. 43-45). Table 4.1.2.2 shows the annual ^{137}Cs concentrations in air collected at Risø since 1958.

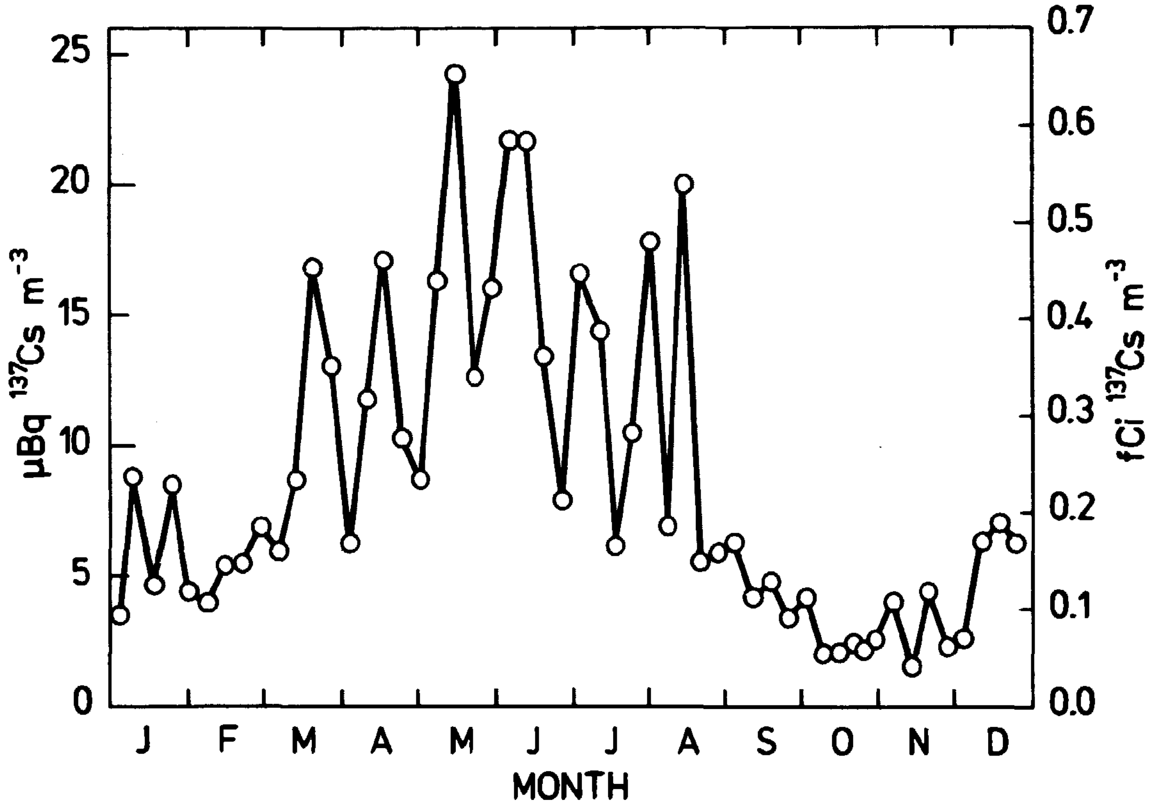

Fig. 4.1.2. Cesium-137 in ground level air at Risø in 1980.

The ^{137}Cs concentrations in air in 1980 were lower than at any other time since measurements began.

Table 4.1.2.2. Cesium-137 in air collected at Risø 1958-1980

Year	fCi m^{-3}	μBq m^{-3}
1958	4.2	155
1959	13.1	480
1960	1.98	73
1961	2.3	84
1962	23	850
1963	66	2400
1964	31	1150
1965	10.6	390
1966	5.7	210
1967	2.1	79
1968	2.4	88
1969	2.4	91
1970	3.4	127
1971	2.7	98
1972	1.37	51
1973	0.47	17.3
1974	1.96	73
1975	1.30	48
1976	0.42	15.5
1977	1.62	60
1978	1.70	63
1979	0.62	23
1980	0.24	8.7

4.1.3. Short-lived γ-emitting nuclides in air

On October 16, 1980, China tested a nuclear weapon in the intermediate range (~ 0.1 Mt) in the atmosphere. Table 4.1.3.1 shows the various short-lived γ-emitters measured in air from Oct 20 to Dec 29, 1980, and Table 4.1.3.2 gives the results from Bornholm. As for ^{137}Cs we notice no local variation (cf. also Table 4.2.7).

Table 4.1.3.1. Short-lived fission products in airborn debris from the Chinese test explosion 16 October 1980 collected in ground level air at Risø, October-December 1980. (Unit: µBq m^{-3})

Date	^{95}Zr	^{95}Nb	^{103}Ru	^{106}Ru	^{131}I	^{140}Ba	^{140}La	^{141}Ce	^{144}Ce
20-24/10			1.1 A		6.5				
24-27/10			2.6		13.8	6 B	3.9		
27/10-3/11	9.0	3.7	13.0		9.9	25	22	12.2	5 B
3-10/11	9.8	4.6	17.1	4 B	9.7	23	22	14.4	6 A
10-17/11	29	16.6	43	6 A	15.3	49	50	41	43 A
17-24/11	147	101	200	13.9	32	177	175	184	40
24/11-1/12	71	61	90	8 A	12.2	62	62	81	21
1-8/12	72	62	77	11.7	9.2	40	39	65	18
8-15/12	320	330	330	35	14.1	140	143	300	93
15-22/12	310	330	330	44	13.9	112	114	290	98
22-29/12	310	350	270	33	4 A	70	66	230	66

Table 4.1.3.2. Short-lived fission products in airborn debris from the Chinese test explosion 16 October 1980 collected in ground level air at Bornholm, October-December 1980. (Unit: µBq m^{-3})

Date	^{95}Zr	^{95}Nb	^{103}Ru	^{106}Ru	^{131}I	^{140}Ba	^{140}La	^{141}Ce	^{144}Ce
21-28/10	2.3	0.7 A	2.8		10.4	6 A	4.0	2.6	
28/10-4/11	8.9	4.2	11.8		11.1	17.0	14.8	8.9	6 A
4-10/11	14.8	7.0	21	5 A	12.2	24	26	18.1	7 A
10-18/11	68	43	87	8 A	25	107	100	87	B.D.L.
18-24/11	144	108	172	12 A	30	150	154	165	38
24/11 1979-2/1 1980	270	330	210	24	B.D.L.	75	81	196	72

4.2. Strontium-90 and various γ-emitters in precipitation

Samples of rain water were collected in 1980 from the State experimental farms (cf. fig. 4.2) in accordance with the principles laid down in Risø Report No. 63, p. 51[1].

Table 4.2.1 shows the results of the ^{90}Sr determinations and Tables 4.2.2 and 4.2.3 the analysis of variance of the results.

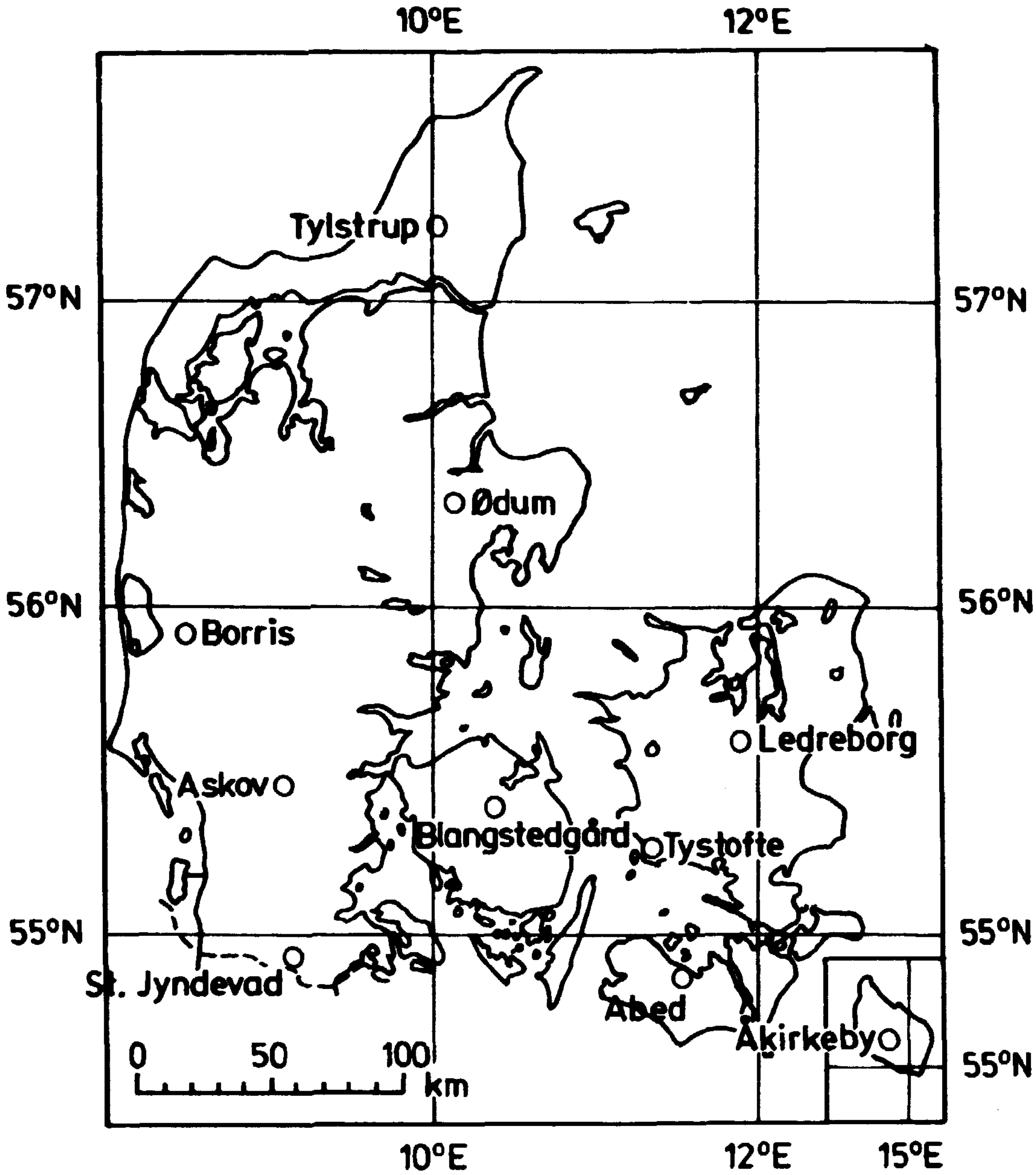

Fig. 4.2. State experimental farms in Denmark.

The maximum concentration in precipitation occurred in March-April when the mean content in precipitation was 11.2 Bq ^{90}Sr m^{-3} (cf. also the air measurements in 4.1.1), and the maximum fallout rate also occurred in May-June, 1.35 Bq ^{90}Sr m^{-2}. The mean levels for ten State experimental farms were 4.3 Bq ^{90}Sr m^{-2} and 5.6 Bq ^{90}Sr m^{-3}. The fallout rate in 1980 was 0.70 times that observed in 1979. The ^{90}Sr deposition in 1980 was 1.5 times higher in Jutland than in the Islands. The ANOVA showed a significant local variation in 1980.

Table 4.2.1. Strontium-90 fall-out in Denmark in 1980 (sampling area at each location: 0.147 m²)

Period	Unit	Tylstrup	Borris	Ødum	Askov	St. Jyndevad	Blangstedgård	Tystofte	Abed	Åkirkeby	Ledreborg	Mean
Jan-Feb	Bq m^{-3}	6.3	3.5	10.4	4.8	6.0	4.1	6.7	7.3	7.3	7.3	5.8
	Bq m^{-2}	0.30	0.26	0.24	0.30	0.34	0.22	0.20	0.26	0.28	0.24	0.26
March-April	Bq m^{-3}	24	9.2	12.2	8.3	8.4	8.0	10.7	11.4	19.2	13.1	11.2
	Bq m^{-2}	0.67	0.44	0.47	0.60	0.57	0.41	0.37	0.55	0.48	0.43	0.50
May-June	Bq m^{-3}	11.6	13.1	11.0	11.8	8.4	14.0	11.5	4.8	11.1	12.9	10.6
	Bq m^{-2}	1.47	2.0	1.35	2.5	1.49	0.69	0.91	0.79	1.28	1.01	1.35
July-Aug	Bq m^{-3}	6.0	4.6	4.7	5.1	5.3	4.5	4.6	3.9	7.3	6.6	5.1
	Bq m^{-2}	0.89	1.00	1.28	1.32	1.32	0.89	0.83	0.62	1.05	0.69	0.99
Sept-Oct	Bq m^{-3}	2.2	5.4	2.2	1.69	2.4	2.4	3.0	3.1	5.8	5.8	3.3
	Bq m^{-2}	0.36	1.46	0.33	0.49	0.70	0.35	0.42	0.50	0.72	0.87	0.62
Nov-Dec	Bq m^{-3}	3.4	3.3	3.2*	2.2*	5.5*	3.9*	3.7*	2.9Δ	5.0	3.0Δ	3.6
	Bq m^{-2}	0.53	0.80	0.49	0.63	1.26	0.60	0.43	0.33	0.84	0.33	0.62
1980	Bq m^{-3} $\bar{x}$	6.3	5.9	5.5	5.0	5.3	4.9	5.4	4.5	7.6	7.0	5.6
	Bq m^{-2} Σ	4.2	6.0	4.2	5.8	5.7	3.2	3.2	3.0	4.6	3.6	4.3
1980	pCi l^{-1} $\bar{x}$	0.17	0.16	0.15	0.13	0.14	0.13	0.15	0.12	0.20	0.19	0.15
	mCi km^{-2} Σ	0.114	0.162	0.114	0.157	0.154	0.086	0.086	0.081	0.124	0.097	0.116
m precipitation Σ		0.666	1.010	0.758	1.174	1.069	0.651	0.583	0.684	0.613	0.510	0.772

Δ1/11-17/12

*m precipitation from Met. Inst. are used for calculation of Bq m^{-2}.

Table 4.2.2. Analysis of variance of ln Bq m^{-3} precipitation in 1980 (from Table 4.2.1)

Variation	SSD	f	s^2	v^2	P
Between months	15.166	5	3.033	33.566	> 99.95%
Between locations	1.734	9	0.193	2.132	> 95%
Remainder	4.066	45			

Table 4.2.3. Analysis of variance of ln Bq m^{-2} precipitation in 1980 (from Table 4.2.1)

Variation	SSD	f	s^2	v^2	P
Between months	15.477	5	3.095	39.415	> 99.95%
Between locations	2.735	9	0.304	3.870	> 99.5%
Remainder	3.534	45			

A comparison between the yearly amounts of precipitation found in the rain gauges used by the Danish Meteorological Institute[9] and the amounts collected in our rain bottles at the same ten locations in 1980 showed a mean ratio of 1.11±0.11 (1 S.D.) between the two sampling systems.

In April 1980 during a sandstorm we measured the soil drift in a height of one meter by weighing the amount of soil collected in the rain bottles at the State experimental farms. The mean amount of soil collected at 8 stations was 20 g m^{-2} (1 S.D.: 18 g m^{-2}), median 13 g m^{-2}. The total area of Denmark is 43,000 km^2. Hence the total amount of soil drift in the country was estimated at 0.02 kg $m^{-2} \times 43 \cdot 10^9$ $m^2 = 0.86 \cdot 10^9$ kg. The ploughing layer contains 0.1 nCi ^{90}Sr kg^{-1}, 0.2 nCi ^{137}Cs kg^{-1}, and 0.005 nCi $^{239,240}Pu$ kg^{-1}. Hence the amounts of activity carried by drift soil in a height of one meter during the storm of April 1980 was approx. 0.1 Ci ^{90}Sr, 0.2 Ci ^{137}Cs, and 5 mCi $^{239,240}Pu$ (or 3 GBq ^{90}Sr, 6 GBq ^{137}Cs, and 0.16 GBq $^{239,240}Pu$). This corresponds to 50-100 ppm of the total inventory of these radionuclides in Danish soils. Compared with the total ^{90}Sr fallout with precipitation in March-April 1980, the contribution from drift soil amounted to approx. 5%. Tables 4.2.4 and 4.2.5 show the ^{90}Sr and ^{137}Cs levels in rain water collected at the 10 m^2 rain collector at Risø.

As compared with the State experimental farms in Zealand (Tystofte and Ledreborg in Table 4.2.1) the ^{90}Sr fallout (Bq m^{-2}) measured at Risø was only 77% and the concentration (Bq m^{-3}) was 81%. The amount of precipitation at Risø was 0.545 m, which was nearly the same as the mean of the Tystofte and Ledreborg values.

The ratio: $^{137}Cs/^{90}Sr$ measured in monthly rain at Risø was 1.29± 0.29 (1 S.D.); in air we found the ratio as 0.85±0.25. Both results are lower than those hitherto observed.

The washout ratios calculated for Risø was $\frac{4.8}{9.9} = 0.48$ for ^{90}Sr and $\frac{6.1}{8.7} = 0.70$ for ^{137}Cs, these values were also lower than the usually observed washout ratio of 1.0. At present, we have no explanations for these deviations from the "normal"

Table 4.2.4. Strontium-90 in rain water collected in a 10 m^2 ion-exchange column collector at Risø in 1980

Period	m	Bq m^{-3}	Bq m^{-2}
January	0.024	4.8	0.115
February	0.020	4.4	0.089
March	0.015	6.5	0.096
April	0.028	6.8	0.189
May	0.010	14.5	0.148
June	0.076	9.2	0.703
July	0.083	5.9	0.486
August	0.041	5.5	0.226
September	0.072	1.79	0.129
October	0.076	1.82	0.139
November	0.061	2.1	0.128
1/12-19/12	0.038	4.0	0.152
1980	Σ 0.545	$\bar{x}$ 4.8	Σ 2.60
1980		pCi l^{-1}: 0.129	mCi km^{-2}: 0.070

Table 4.2.5. Cesium-137 in rain water collected in a 10 m^2 ion-exchange column collector at Risø in 1980

Period	m	Bq m^{-3}	Bq m^{-2}
January	0.024	4.7	0.112
February	0.020	5.6	0.114
March	0.015	9.6	0.143
April	0.028	10.8	0.30
May	0.010	13.7	0.140
June	0.076	9.9	0.76
July	0.083	8.1	0.67
August	0.041	6.7	0.27
September	0.072	2.8	0.21
1/10-27/10	0.048	2.8	0.137
27/10-31/10	0.028	1.15	0.033
November	0.061	3.7	0.23
1/12-19/12	0.038	3.7	0.141
1980	Σ 0.545	$\bar{x}$ 6.1	Σ 3.26
1980		pCi l^{-1}: 0.165	mCi km^{-2}: 0.089

values; however, the relatively large amount of precipitation in 1980 (~ 30% more than normal) may have lowered the washout ratio.

Tables 4.2.4 and 4.2.5 show the ^{90}Sr and ^{137}Cs levels in rain water collected at the 10 m^2 rain collector at Risø. As compared with the State experimental farms in Zealand (Tystofte and Ledreborg in Table 4.2.1) the ^{90}Sr fallout (Bq m^{-2}) measured at Risø was only 77% and the concentration (Bq m^{-3}) was 81%. The amount of precipitation at Risø was 0.545 m which was nearly the same as the mean of Tystofte and Ledreborg.

In order to investigate the distribution of fresh fallout in the 10 m^2 deposition collector at Risø, we measured the fallout from the Chinese test explosion of Oct 16, 1980. Precipitation was collected in the period Oct 27 to 31. Measurements were performed separately on 1: the dust remaining on the surface of the collector, 2: the prefilter before the ion-exchange column, 3: the ion-exchange column resin, and 4: the effluent from the column. The dust on the surface of the collector was washed off with 9 l 1% HNO_3 and divided into an AMP-fraction and a $Fe(OH)_3$ precipitate, and the effluent from the column (cf. Table 4.2.7) was divided as well.

Table 4.2.6. Short-lived γ-emitting nuclides in rain water collected in the 10 m^2 ion-exchange column collector at Risø in 1980

Isotope	1-27/10		27-31/10		November		1-19/12	
	Bq m^{-3}	Bq m^{-2}	Bq m^{-3}	Bq m^{-2}	Bq m^{-3}	Bq m^{-2}	Bq m^{-3}	Bq m^{-2}
^{95}Zr	1.22	0.059	23	0.65	74	4.5	115	4.4
^{95}Nb	0.3 B	0.02 B	7.4	0.21	65	4.0	126	4.8
^{103}Ru	6.5	0.31	39	1.11	155	9.5	174	6.6
^{106}Ru					14.1	0.86	17.0	0.65
^{131}I	33	1.58	46	1.31	65	4.0	14.1	0.54
^{140}Ba	26	1.25	58	1.65	185	11.3	87	3.3
^{140}La	23	1.10	44	1.25	189	11.5	88	3.3
^{141}Ce	1.26	0.060	32	0.91	74	4.5	85	3.2
^{144}Ce					21	1.28	31	1.18

Table 4.2.7. Radionuclides in fresh fall-out in various fractions (cf. the text) collected by the 10 m^2 rain collector at Risø in the period 27-31 October 1980. The results (Bq m^{-2}) are referred back to the day of the test explosion (16 Oct 1980)

Radionuclide	Dust washed off from the surface of the 10 m^2 collector				Prefilter		Ion-exchange column (resin)		Effluent from column				Total deposit Σ
	AMP fraction		$Fe(OH)_3$-fraction						AMP fraction		$Fe(OH)_3$-fraction		
	Bq m^{-2}	%	Bq m^{-2}	%	Bq m^{-2}	%	Bq m^{-2}	%	Bq m^{-2}	%	Bq m^{-2}	%	Bq m^{-2}
^{7}Be	0.09	0	1.20	3	2.98	9	31.07	88	-	0	0.1	0	35
^{95}Zr	0.05	7	0.02	3	0.12	16	0.35	47	0.10	13	0.11	14	0.75
^{95}Nb*	0.02	8	0.01	4	0.06	25	0.07	29	0.04	17	0.04	17	0.24
^{103}Ru	0.01	1	0.01	1	0.07	5	1.13	80	0.03	2	0.15	11	1.40
^{131}I	0.06	1	-	0	0.74	18	2.65	66	0.49	12	0.10	3	4.04
^{140}Ba	0.15	4	0.26	8	0.49	15	2.48	73	-	0	-	0	3.38
^{140}La*	0.04	2	0.26	10	0.51	20	1.70	66	0.04	2	-	0	2.55
^{141}Ce	0.11	9	0.58	48	0.33	27	0.10	8	0.03	3	0.06	5	1.21

Radionuclide ratios on Oct 16, 1980	Rain 27-31/10-80	Air(±1 S.D.) 28/10-1/12-80	Theoretical ratios at formation[4]
$^{141}Ce/^{95}Zr$	1.6	1.76±0.24	1.77
$^{140}Ba/^{95}Zr$	4.5	6.20±1.95	5.2
$^{131}I/^{95}Zr$	5.4	5.07±1.53	4.6
$^{103}Ru/^{95}Zr$	1.9	1.76±0.46 (10 samples)	1.67

*Decay corrected with half life of parent nuclide.

It appears that the parts of the ion-exchange system normally measured, i.e. prefilter and resin collect 97% of ^{7}Be, 63% ^{95}Zr, 54% ^{95}Nb, 85% ^{103}Ru, 84% ^{131}I, 88% ^{140}Ba, 86% ^{140}La and 35% ^{141}Ce. The system is thus inadequate for collecting ^{141}Ce, ^{95}Zr and ^{95}Nb. Most of the ^{141}Ce adhered to the surface of the 10 m^2 collector (57%). To a considerable degree ^{95}Zr and ^{95}Nb passed through the column without being collected, 27% in the case of ^{95}Zr and 34% for ^{95}Nb.

We cannot preclude that the total deposits estimated from the 6 measurements of the various radionuclides may have been lower than the actual deposit because the AMP and $Fe(OH)_3$ precipitations may not have collected all activity from the wash water and the effluent. However, the ratios shown at the bottom of the table indicate that the measured ratios in rain are close to those in air (and to the theoretical ones). Hence we assume that we have recovered essentially all activity by the method applied, because it would be highly unlikely that radionuclides, which behave so differently in the ion-exchange system, should come out with the correct ratios if some of the activity had not been accounted for by the analysis.

We conclude further that initially none of the four ratios differed significantly from the theoretical ones.

As regards the resin's efficiency of collecting ^{137}Cs, during 1980 we have determined ^{137}Cs in the effluent by AMP precipitation. We found no indication of ^{137}Cs in the effluent, but some ^{137}Cs (and ^{90}Sr) may stick to the 10 m^2 surface of the collector. This will be examined further.

4.3. Fresh water

4.3.1. Strontium-90 in ground water

As in previous years[1)], ground water was collected in March from the nine locations selected by the Geological Survey of Denmark. Figure 4.3.1.1 shows the sample locations and Table 4.3.1 the results of the ^{90}Sr analyses.

The median level of ^{90}Sr in 1980 was compatible with the values found since 1967 (cf. fig. 4.3.1.2).

As appears from fig. 4.3.1.3, the ^{90}Sr levels in ground water from Feldbak have been around 50-75 Bq m^{-3} in later years except in 1978 where we found about 100 Bq ^{90}Sr m^{-3}. ^{137}Cs was not measurable in 45 l samples of Feldbak water from 1977, 1978, 1979, 1980 and 1981; the levels must have been less than 7.4 Bq ^{137}Cs m^{-3}.

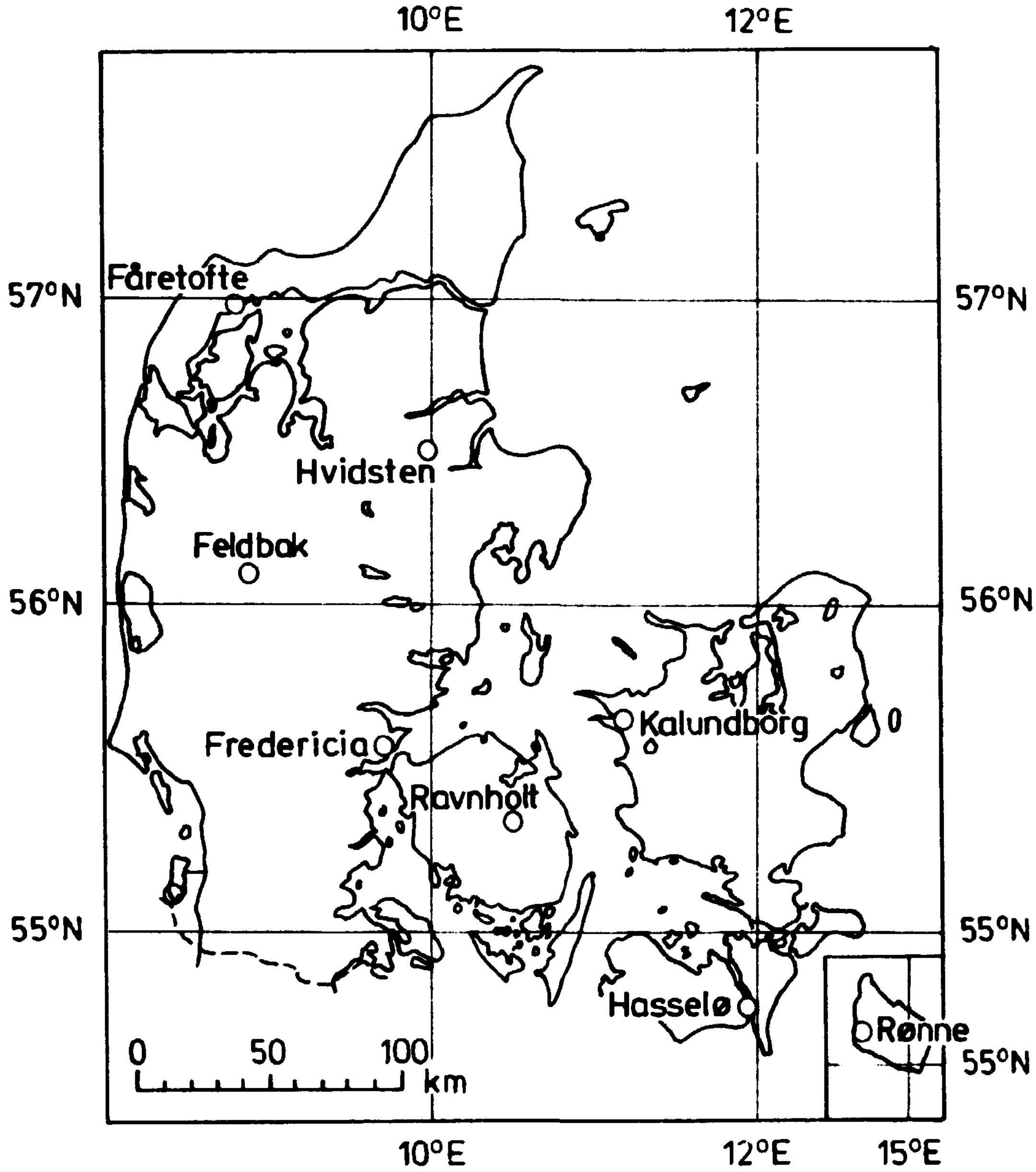

Fig. 4.3.1.1. Ground water sampling locations in Denmark.

Table 4.3.1. Strontium-90 in ground water collected in March 1980

Location	Bq m^{-3}	kg Ca m^{-3}
Hvidsten	0.070	0.054
Feldbak	67	0.030
Rømø	0.03 B	0.040
Rønne new	0.141	0.011
Rønne old	0.141 A	0.025
Hasselø	0.070	0.116
Fåretofte	0.033 A	0.092
Kalundborg	2.4	0.093
Ravnholt	0.13 B	0.097
Fredericia	0.66	0.071
Geometric mean	0.14*	0.063**
Median	0.14	0.062
Geometric mean: pCi l^{-1}	0.0038	
Median: pCi l^{-1}	0.0038	

A sample of ground water from Maglekilde in Roskilde contained 0.65 Bq ^{90}Sr m^{-3} and 0.194 kg Ca m^{-3}. In June a sample of ground water from Kalundborg contained 10.2 Bq ^{90}Sr m^{-3} and 0.041 kg Ca m^{-3}.

* Feldbak was not included in the geometric mean.

**Arithmetic mean.

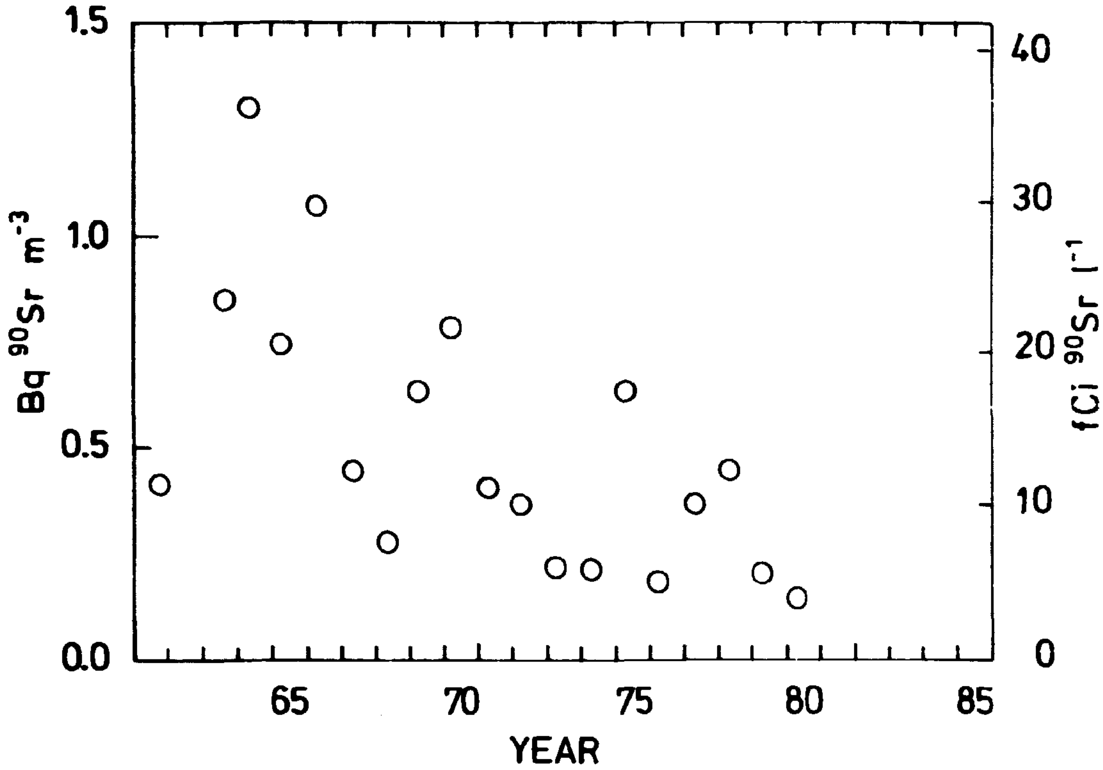

Fig. 4.3.1.2. Median ^{90}Sr levels in Danish ground water, 1961-1980.

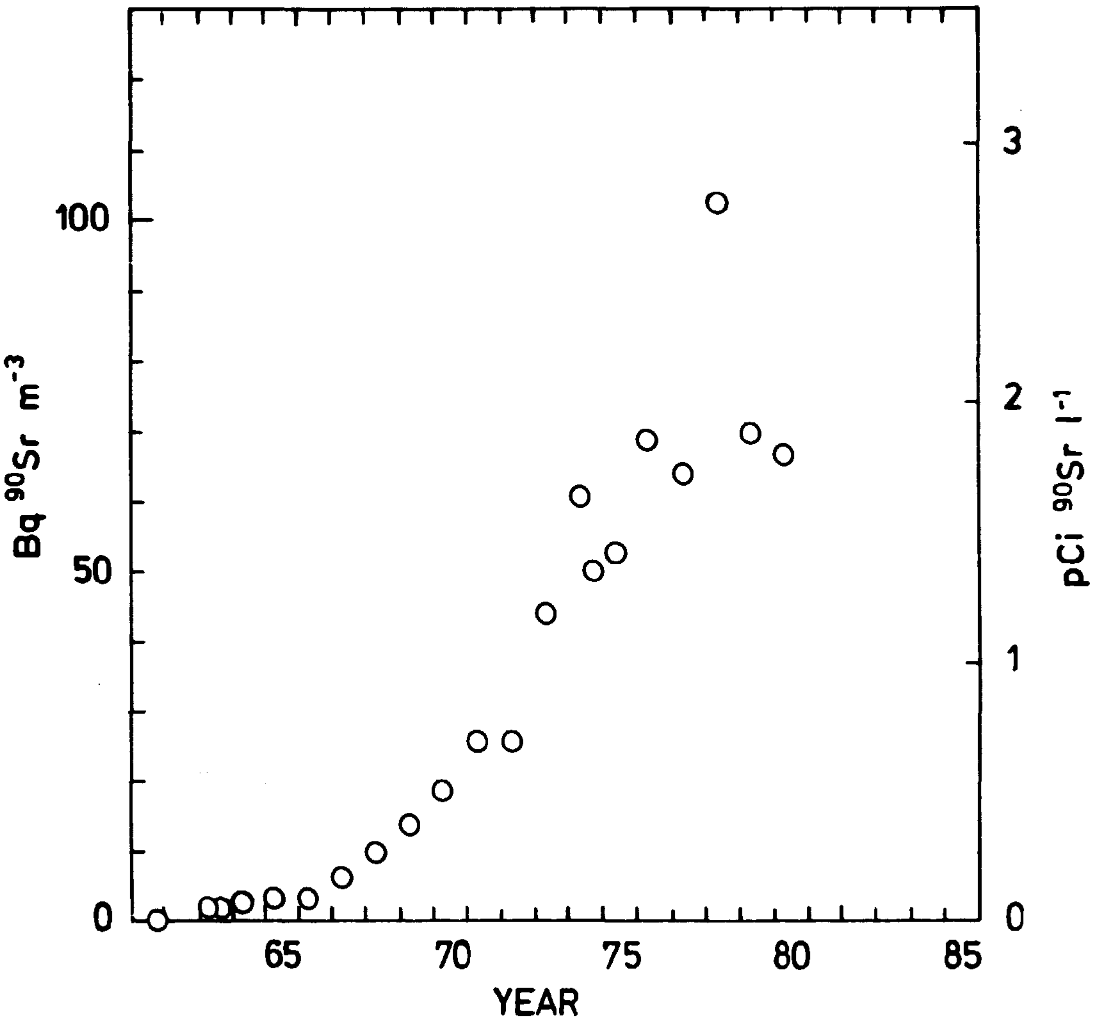

Fig. 4.3.1.3. Strontium-90 in ground water at Feldbak 1961-1980.

4.3.2. Cesium-137 in fresh water from Danish lakes

In February 1980 we collected fresh water from Danish lakes (sø) from the locations shown in fig. 4.3.2.1. The results are shown in Table 4.3.2. The purpose was to compare the ^{137}Cs and the ^{90}Sr concentrations in lake water. As the ^{90}Sr levels in lake water has been rather constant in later years we used the ^{90}Sr results from 1979 for the comparison. The ^{137}Cs/^{90}Sr mean ratio was 0.16±0.14 (1 S.D.). The lowest ratios (~ 0.04) were found in Norssø and in Almindingen; the highest ratio (~ 0.40) was observed in Flyndersø.

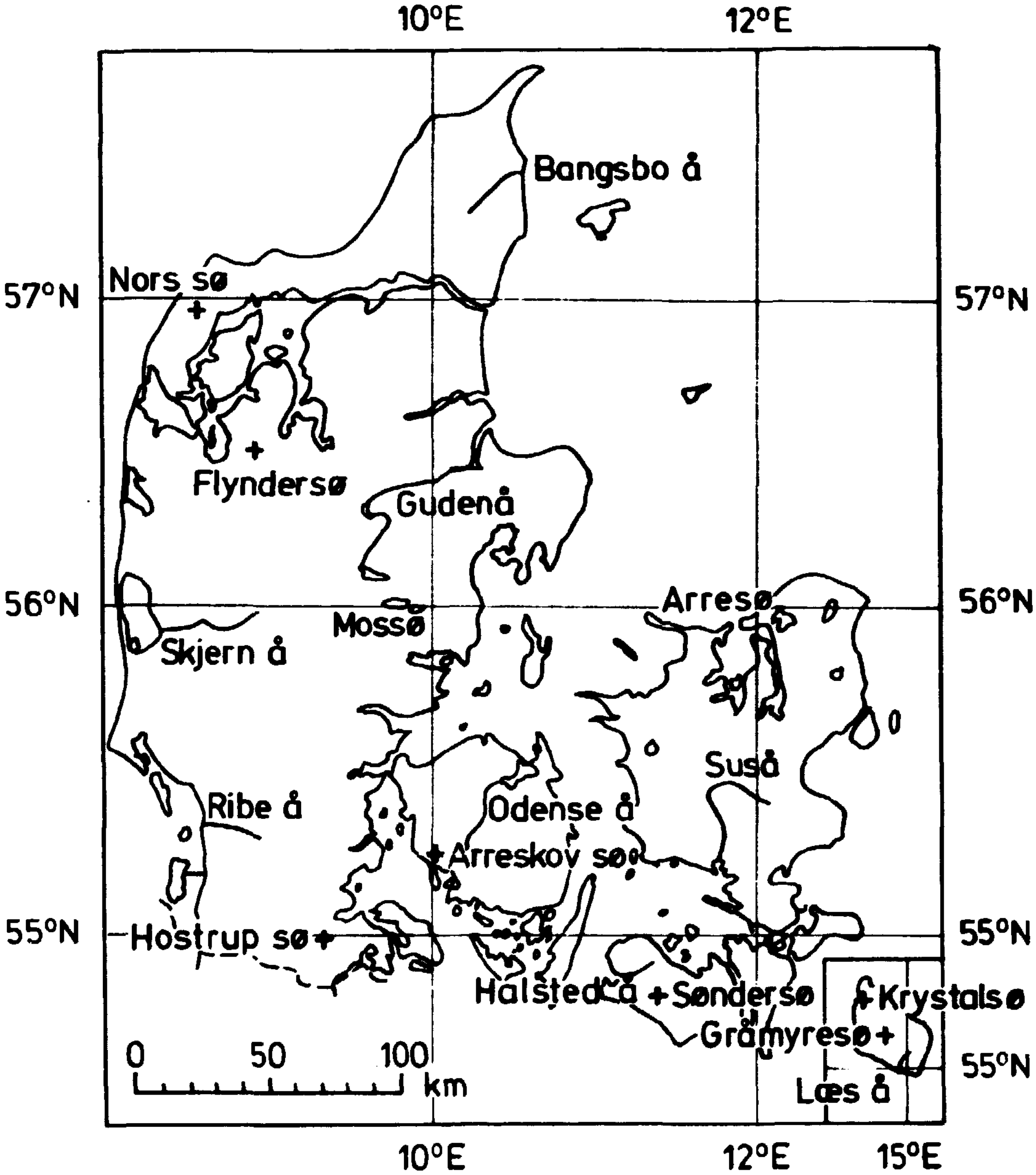

Fig. 4.3.2.1. Sample locations for fresh water from Danish streams (å) and lakes (sø).

Table 4.3.2. Cesium-137 in Danish lakes collected in 1980

Zone			Date	Bq m^{-3}
I:	North Jutland	Norsse	1/9	3.3
II:	East Jutland	Mosse	3/9	3.0
III:	West Jutland	Flynderse	2/9	3.7
IV:	South Jutland	Hostrup se	4/9	12.2
V:	Funen	Arreskov se	9/9	2.7
VI:	Zealand	Arrese	28/8	9.8
VII:	Lolland-Falster	Sønderse	10/9	3.8
VIII:	Bornholm	Almindingen	19/8	1.22
Mean				4.9
±1 S.E.				1.4
Mean: pCi l^{-1}				0.135
±1 S.E.				0.037

4.4. Strontium-90, Cesium-137 and Cesium-134 in sea water in 1980

As in previous years, sea water samples were collected by M/S Pyrholm in the summer from inner Danish waters (cf. Table 4.4.1 and figs. 4.4.1 and 4.4.2). Furthermore, sea water samples were collected at Barsebäck in the Sound (Table 4.4.2), and at Ringhals in the Kattegat (Table 4.4.3). Samples from the North Sea were obtained from the State ships "Nordjylland" and "Havørnen" (fig. 4.4.4 and Table 4.4.4).

Figure 4.4.2 shows that the maximum ^{137}Cs concentration in bottom water occurred in 1979, since then the levels have decreased. According to BNFL[37] the maximum release from Windscale took place in 1975 (~ 5.2 PBq ^{137}Cs). In 1976-78 the annual releases had decreased to about 4 PBq and in 1979 further down to 2.7 PBq. Hence we conclude that the transport time to Danish waters from Windscale is approximately 4 years, i.e. in agreement with last year's estimate. We may further conclude that the inflow from the North Sea (500 km^3 y^{-1}) carried (500 × 10^9 m^3 × $\frac{86+60}{2}$ Bq m^{-3}) =

Table 4.4.1. Strontium-90, Cesium-137 and Cesium-134 in sea water collected around Zealand in August and November-December 1980

	Position		August					November-December				
	N	E	Depth in m	^{90}Sr Bq m^{-3}	^{137}Cs Bq m^{-3}	^{134}Cs Bq m^{-3}	Salinity o/oo	Depth in m	^{90}Sr Bq m^{-3}	^{137}Cs Bq m^{-3}	^{134}Cs Bq m^{-3}	Salinity o/oo
Kullen	56°15'	12°25'	0	28	41	1.6 B	16.4	0	17.8	67	2.8	21.9
"			21	29	113	5.4	34.0	22	17.0	Lost	Lost	24.1
Hesselø	56°10'	11°47'	0	30	48	2.1 A	17.7	0	12.4	68	3.4	24.3
"			24	32	106	4.6	34.1	25	29	108	5.1	33.0
Kattegat SW	56°07'	11°10'	0	23	38	B.D.L.	14.4	0	16.8	50	2.4 A	23.9
"			39	29	112	4.5	28.4	33	lost	51	2.6	32.1
Asnæs rev	55°38'	10°47'	0	lost	35	B.D.L.	12.7	0	26	67	3.1	22.1
" "			39	lost	105	5.5	30.9	35	28	95	4.2	30.7
Halskov rev	55°23'	11°03'	0	lost	26	B.D.L.	10.8	0	16.3	48	2.2 B	18.8
" "			19	34	91	5.2	29.2	20	17.1	73	2.8	24.3
Langeland bælt	54°52'	10°50'	0	33	23	B.D.L.	9.2	0	24	49	2.3	18.4
" "			48	31	93	5.0	29.7	45	27	53	2.8 A	18.6
Femern bælt	54°36'	11°05'	0	20	30	1.7 B	12.0	0	17.3	37	2.3 A	16.9
" "			28	22	88	5.1	28.8	20	16.3	48	2.2 B	14.0
Gedser odde	54°28'	11°59'	0	13.8	17.6	B.D.L.	8.2	0	25	33	B.D.L.	13.4
" "			18	19.8	75	3.2	27.3	18	lost	40	B.D.L.	14.9
Møen	54°57'	12°41'	0	17.4	18.2	B.D.L.	7.9	0	24	23	B.D.L.	9.3
"			21	15.2	18.1	B.D.L.	7.8	21	26	26	B.D.L.	11.2
The Sound - South	55°25'	12°39'	0	31	31	1.4 A	11.1	0	24	27	B.D.L.	11.2
" " "			12	lost	33	B.D.L.	12.5	12	25	28	B.D.L.	11.9
The Sound - North A	55°48'	12°44'	0	28	41	2.5 A	13.6	0	18.9	63	2.9	19.5
" " "			19	32	89	4.4	27.2	20	19.1	62	2.6	22.6
The Sound - North B	55°59'	12°42'	0	24	23	B.D.L.	10.7	0	21	67	3.0	21.3
" " "			26	lost	114	5.4	32.9	25	26	79	3.4	27.3
Mean			Surface	25	31		12.1		20	50		18.4
S.D.				6.3	9.5		3.1		4.3	16.7		4.9
S.E.				2.0	2.7		0.9		1.2	4.8		1.4
Mean			Bottom	27	86		26.9		23	60		22.1
S.D.				6.5	31		8.2		5.1	26		7.9
S.E.				2.2	9.0		2.4		1.6	7.9		2.3
Mean: pCi l^{-1}			Surface	0.67	0.85				0.55	1.35		
S.D.				0.17	0.26				0.12	0.45		
S.E.				0.05	0.07				0.03	0.13		
Mean: pCi l^{-1}			Bottom	0.73	2.34				0.62	1.63		
S.D.				0.18	0.84				0.14	0.71		
S.E.				0.06	0.24				0.04	0.21		

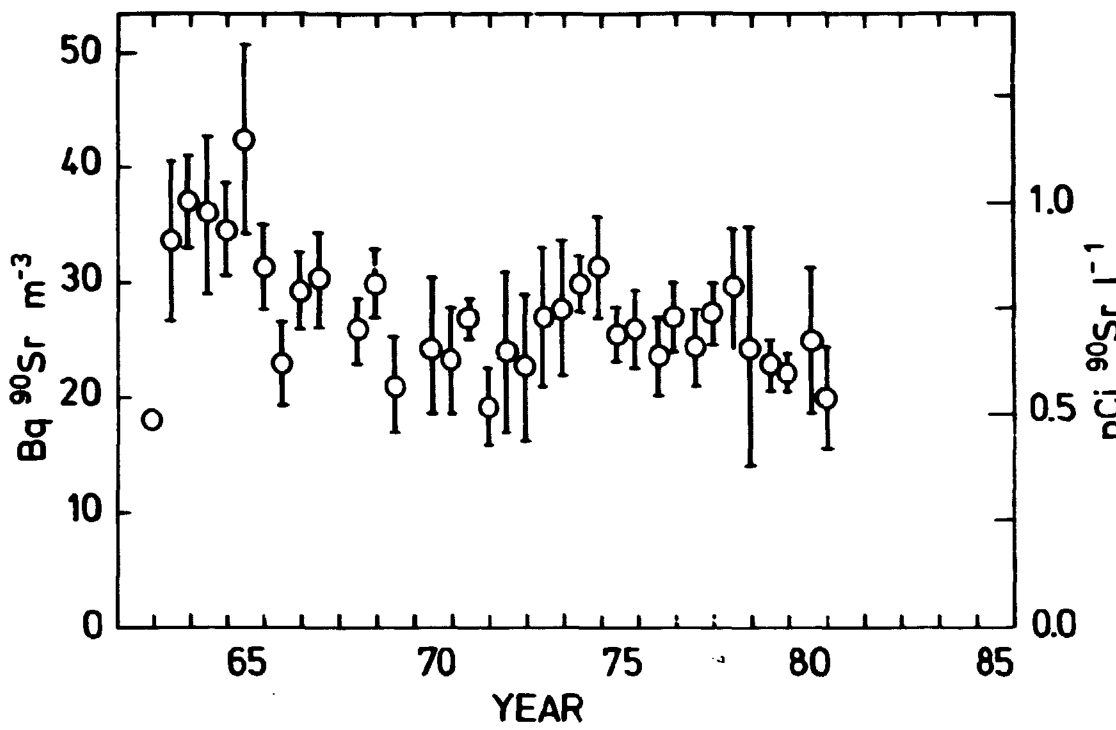

Fig. 4.4.1. Strontium-90 in surface sea water from inner Danish waters, 1962-1980. (1 S.D. indicated) (from Table 4.4.1).

36.5 × 10^{12} Bq in 1980 or 0.85% of the discharge from Windscale in 1976, i.e. around 1% of the ^{137}Cs from Windscale enters the Baltic Sea.

From July-August to November-December the 50 Bq ^{137}Cs m^{-3} iso-curve in Danish surface water moved from a line Hals - south of Læsø - Göteborg to just North of Zealand, i.e. a distance of approximately 150 km, in five months or 1 km d^{-1} (~ 1 cm s^{-1}). The mean ratio: ^{134}Cs/^{137}Cs in Danish sea water in 1980 was 0.047 and the relative S.D. was approximately 10%.

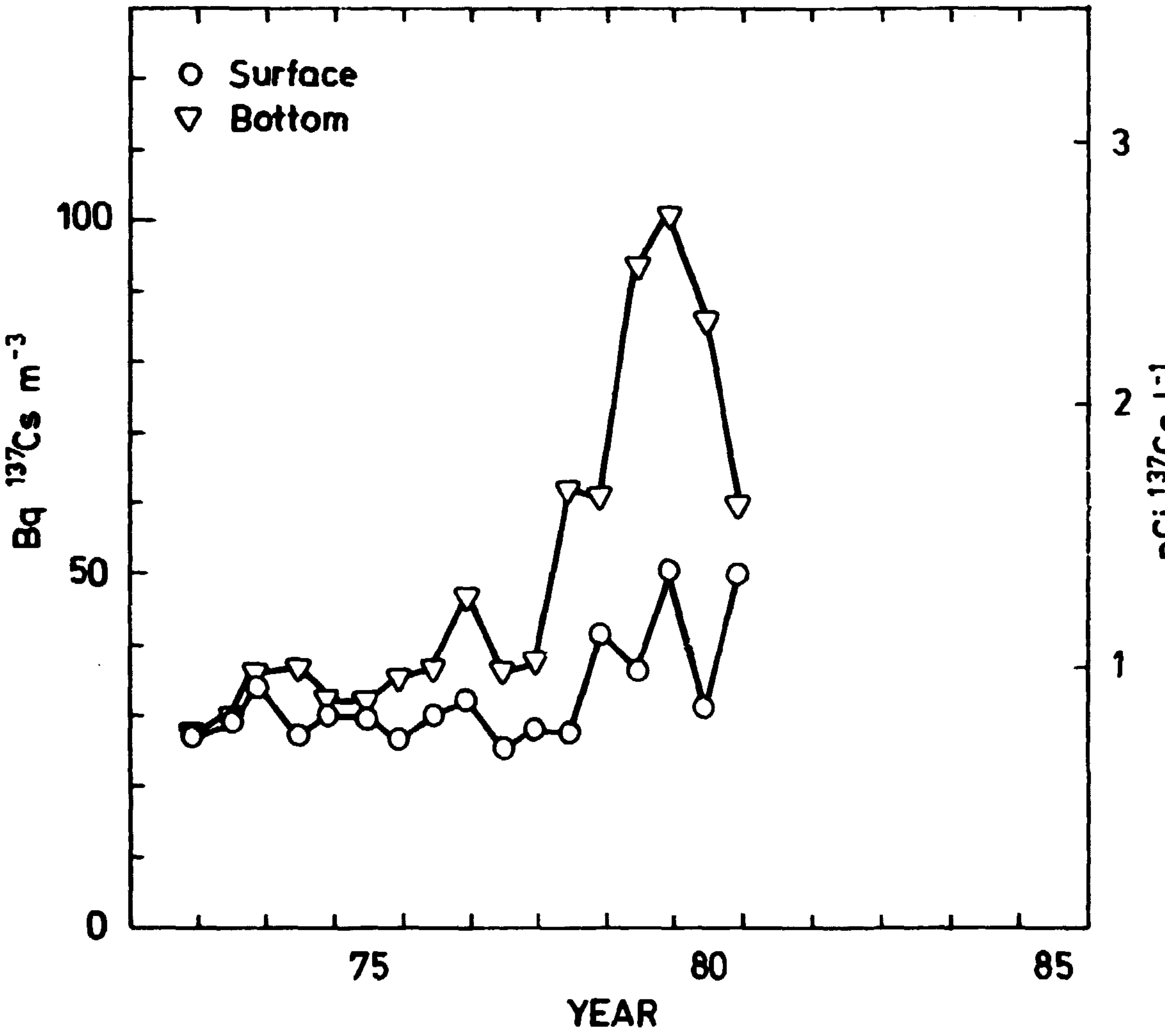

Fig. 4.4.2. Cesium-137 in surface and bottom water collected in inner Danish waters 1972-1980.

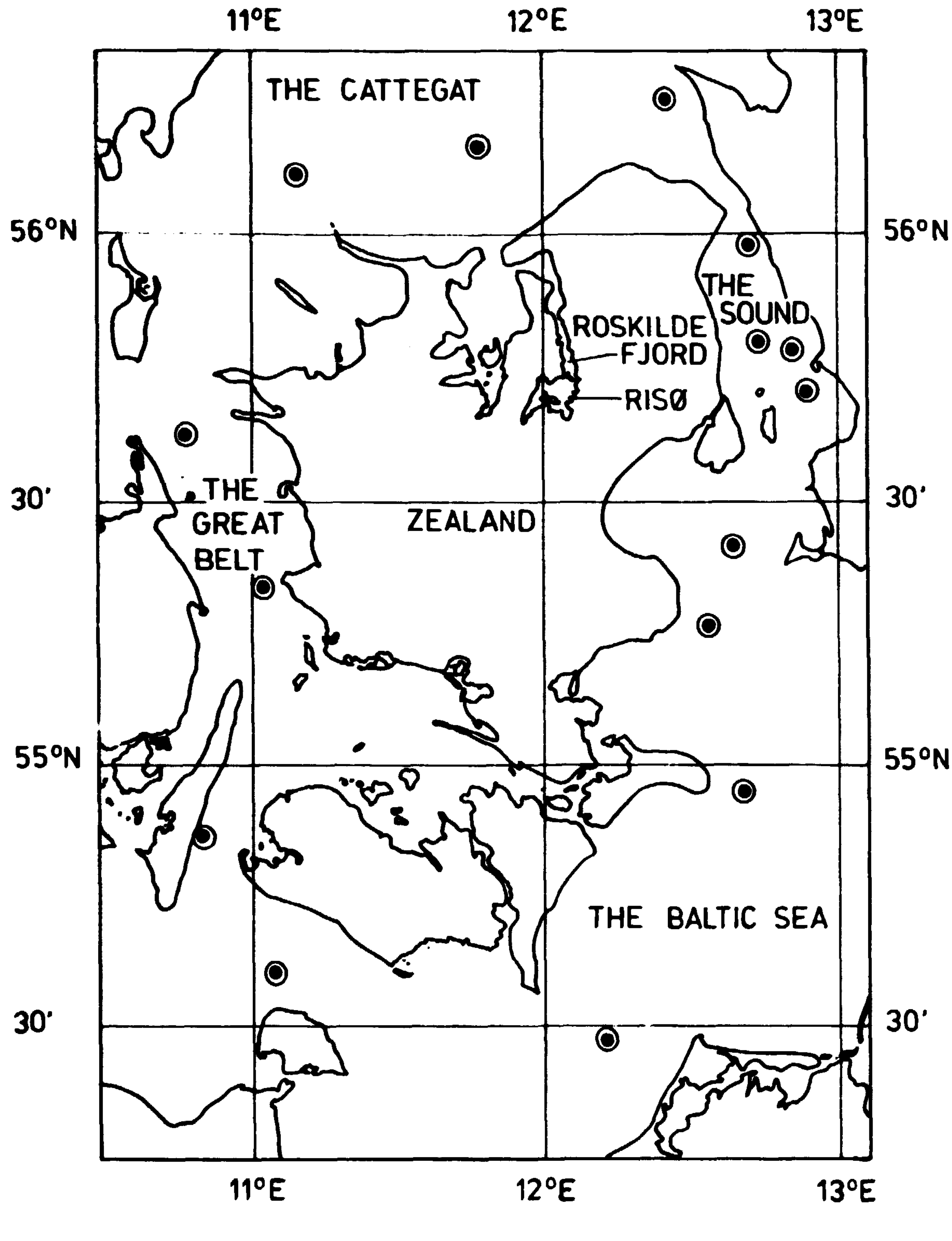

Fig. 4.4.3. Sea water locations around Zealand.

Table 4.4.2. Strontium-90, Cesium-137 and Cesium-134 in sea water collected in the Sound at Barsebäck, location 38 (cf. Fig. 3.2.1) in 1980

Date	Depth in m	^{90}Sr Bq m^{-3}	^{137}Cs Bq m^{-3}	^{134}Cs Bq m^{-3}	Salinity o/oo
8/8	0	36	36	-	13.1
"	16	101	104	-	31.6
20/12	0	17.6	28	B.D.L.	11.2
"	16	18.5	57	2.9	19.2

Table 4.4.3. Cesium-137 and Cesium-134 in sea water collected at Ringhals in 1980

Samling location (cf. Fig. 3.2.2)	July 20				October 11			
	Depth in m	^{137}Cs Bq m^{-3}	^{134}Cs Bq m^{-3}	Salinity o/oo	Depth in m	^{137}Cs Bq m^{-3}	^{134}Cs Bq m^{-3}	Salinity o/oo
0*	0	53	2.4	20.8	0	78	2.5	30.0
"	66	112	5.4	35.3	65	108	5.2	33.0
2					0	56	2.6	18.6
"					22	82	4.1	29.7
Mean: Surface		53	2.4	20.8	Surface	67	2.6	24.3
S.D.						16	0.07	8.1
S.E.						11	0.05	5.7
Mean: Bottom		112	5.4	35.3	Bottom	95	4.6	31.4
S.D.						18	0.78	2.3
S.E.						13	0.55	1.6
Mean: Surface					Surface	1.81	0.069	
S.D. pCi l^{-1}						0.42	0.002	
S.E.						0.30	0.001	
Mean: Bottom					Bottom	2.57	0.126	
S.D. pCi l^{-1}						0.50	0.021	
S.E.						0.35	0.015	

*57°14'N 11°53'7E

Table 4.4.4. Cesium-137 and Cesium-134 in surface sea water collected at Cattegat in July 1980

Position N	Position E	Date	^{137}Cs Bq m^{-3}	^{134}Cs Bq m^{-3}	Salinity o/oo
57°19'	11°37'	21/7	52	2.5 A	21.6
57°25'	11°22'	"	63	3.0	23.3
57°31'	11°07'	"	70	3.6	30.8
57°37'	10°52'	"	71	3.3 A	27.1
57°42'	10°38'	"	73	3.6	30.6
57°28'	10°42'	24/7	74	3.7	26.5
57°13'	10°44'	"	62	2.1 A	20.8
56°59'	10°52'	"	46	2.0 B	18.1
56°46'	11°04'	"	50	2.2 B	18.1
56°33'	11°17'	"	48	1.4 B	18.0
56°19'	11°30'	"	50	2.0 A	19.5

As was done earlier we calculated the regression equations between salinity and ^{90}Sr and ^{137}Cs activity in the sea water:

Bq ^{90}Sr m^{-3} = 34.8-0.67 o/oo (1967-1971)
Bq ^{90}Sr m^{-3} = 35.9-0.74 o/oo (1972)
Bq ^{90}Sr m^{-3} = 35.2-0.52 o/oo (1973)
Bq ^{90}Sr m^{-3} = 34.4-0.37 o/oo (1974)
Bq ^{90}Sr m^{-3} = 29.2-0.22 o/oo (1975)
Bq ^{90}Sr m^{-3} = 26.3-0.074 o/oo (1976)
Bq ^{90}Sr m^{-3} = 26.3-0.056 o/oo (1977)
Bq ^{90}Sr m^{-3} = 27.8-0.107 o/oo (1978)
Bq ^{90}Sr m^{-3} = 27.8-0.31 o/oo (1979)
Bq ^{90}Sr m^{-3} = 20.8+0.159 o/oo (1980)

The regression analysis showed only significant regression in 1967-1971, 1972 and in 1974.

Bq ^{137}Cs m^{-3} = 29.6-0.16 o/oo (1972)
Bq ^{137}Cs m^{-3} = 22.2+0.44 o/oo (1973)
Bq ^{137}Cs m^{-3} = 20.0+0.67 o/oo (1974)
Bq ^{137}Cs m^{-3} = 23.7+0.37 o/oo (1975)
Bq ^{137}Cs m^{-3} = 19.6+0.70 o/oo (1976)

$$\text{Bq } ^{137}\text{Cs m}^{-3} = 15.2+1.00 \text{ o/oo } (1977)$$
$$\text{Bq } ^{137}\text{Cs m}^{-3} = -10.4+2.85 \text{ o/oo } (1978)$$
$$\text{Bq } ^{137}\text{Cs m}^{-3} = -33.3+4.44 \text{ o/oo } (1979)$$
$$\text{Bq } ^{137}\text{Cs m}^{-3} = -9.1+3.26 \text{ o/oo } (1980)$$

The regression analysis showed significant or probably significant regression in all years except in 1972.

Table 4.4.5. Strontium-90, Cesium-137 and Cesium-134 in surface sea water collected by "Havørnen" in the North Sea in 1980

Position N	Position E	Date	^{90}Sr Bq m^{-3}	^{137}Cs Bq m^{-3}	^{134}Cs Bq m^{-3}	Salinity o/oo
55°57'	03°30'	5/9-1980	-	210	11.4	35.1
55°13'	08°12'	26/1-1981	20	32	1.3 A	29.5
55°55'	05°57'5	27/1-1981	44	250	10.8	34.5

Table 4.4.6. Strontium-90, Cesium-137 and Cesium-134 in surface sea water collected at different locations in 1980

Location	Date	^{90}Sr Bq m^{-3}	^{137}Cs Bq m^{-3}	^{134}Cs Bq m^{-3}	Salinity o/oo
Listed, Bornholm	19/8		17.0	B.D.L.	8.8
Risø mole	26/8		25.2	B.D.L.	
Risø I*	July	36	24.8	B.D.L.	13.9

*Cf. Fig. 4.6.2.

According to the above regression lines, the mean levels in Danish surface waters (16 o/oo salinity) were estimated at 23 Bq ^{90}Sr m^{-3} and 43 Bq ^{137}Cs m^{-3} in 1980. The corresponding levels in North Sea water (34 o/oo) were 26 and 102, respectively, and in Baltic water (9 o/oo) the equations gave 22 and 6.7, respectively (cf. fig. 4.4.6).

Figure 4.4.7 shows that the concentrations in 35 o/oo Danish sea water could be predicted from the discharges of ^{137}Cs from Windscale.

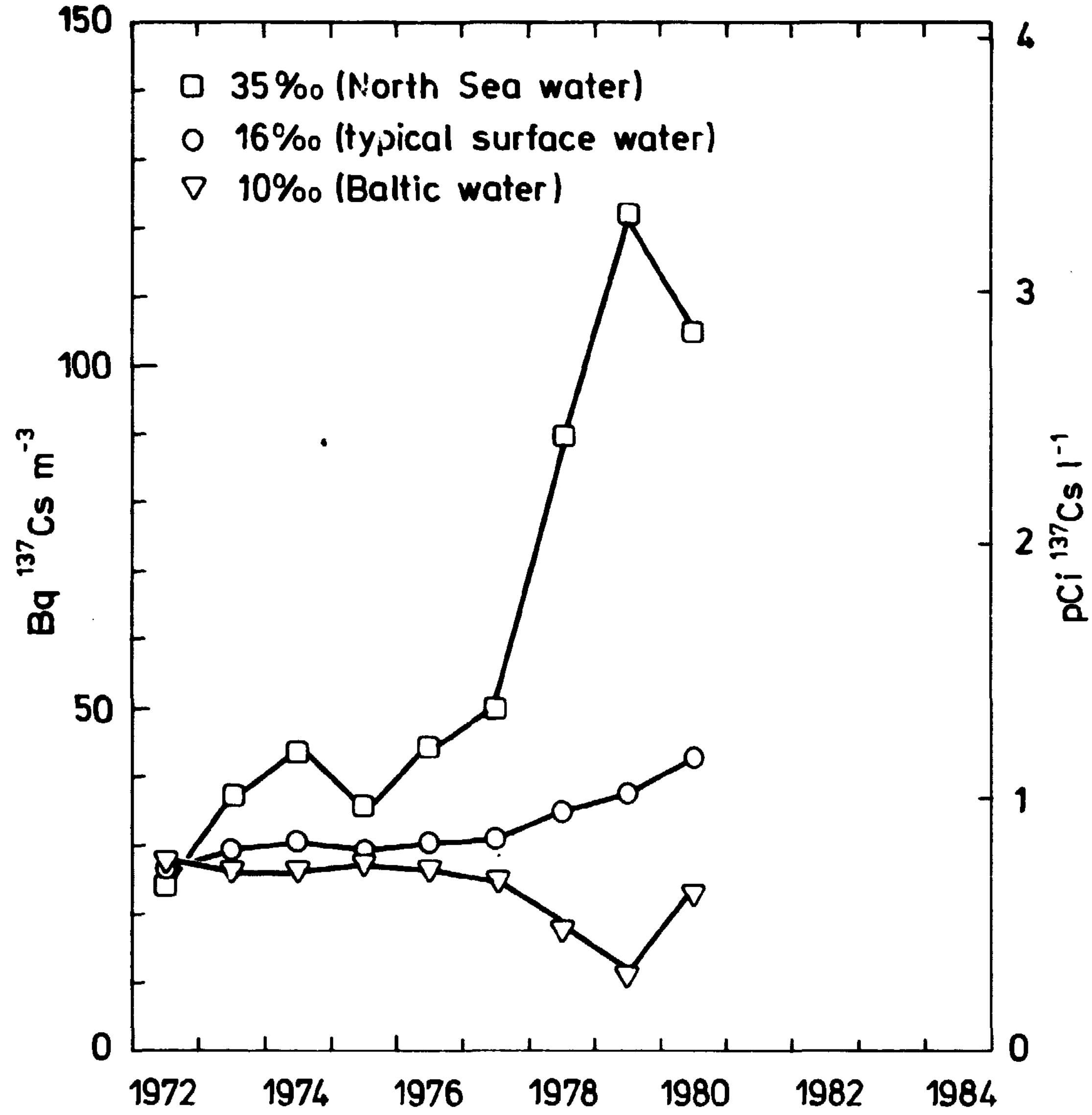

Fig. 4.4.6. Cesium-137 in inner Danish waters of 3 different salinities (1972-1980). The values were calculated from the regression equations in 4.4.

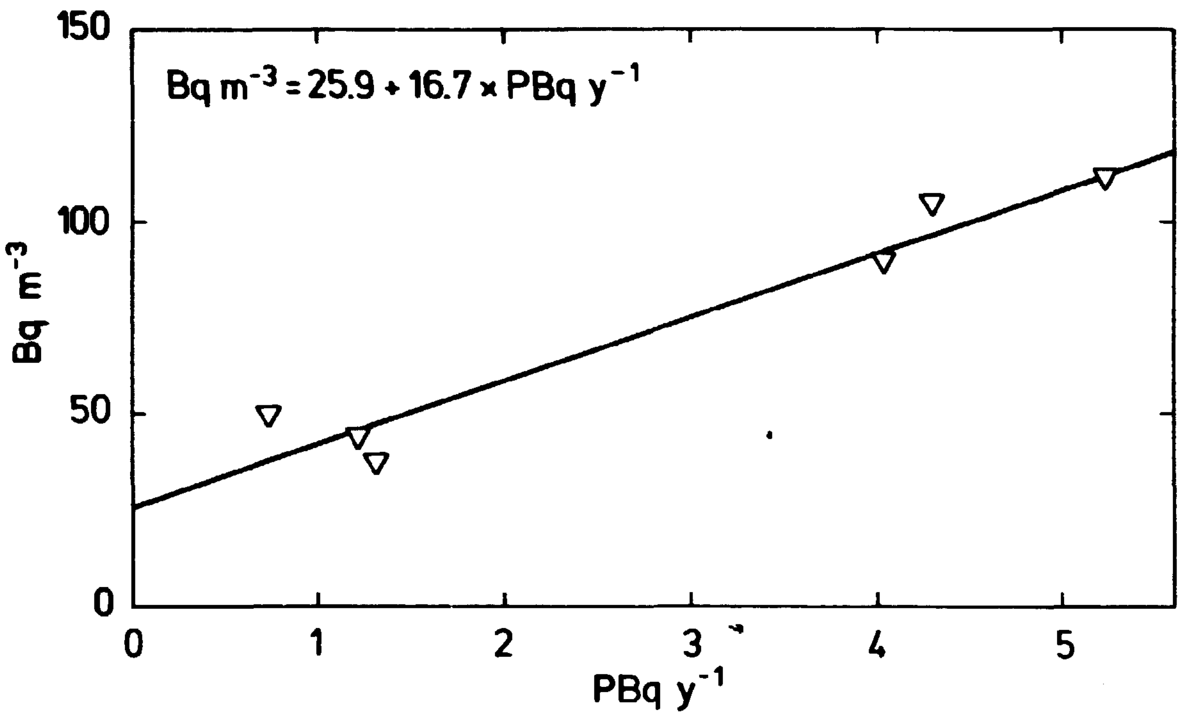

Fig. 4.4.7. Cesium-137 in 35 o/oo Danish sea water (Bq m^{-3}) during 1975-1980 related to the Windscale discharges of ^{137}Cs (PBq y^{-1}) 4 years earlier (1971-1976).

4.5. Strontium-90 in soil collected in 1978

As described in Risø-R-403[1)] p. 60 soil samples were collected in 1978 at St. Jyndevad (cf. fig. 4.2) in two trenches, A and B, each approximately 4 m long, 1.5 m wide, and 2 m deep. We reported the ^{137}Cs and $^{239,240}Pu$ results earlier in Risø-R-403. Table 4.5 presents the ^{90}Sr data from trench A. The ^{90}Sr levels were surprisingly low both as compared with the ^{137}Cs and $^{239,240}Pu$ concentrations, but also compared with earlier soil measurements at St. Jyndevad (cf. Risø Report No. 345[1)]). The ^{90}Sr activity seems to have moved to greater depths than ^{137}Cs and $^{239,240}Pu$, which were not detected below 30 cm. The penetration may even be beyond 100 cm. This may explain that we found only 819±12 Bq ^{90}Sr m^{-2} (±1 S.E., mean of A_1 and A_2) down to 1 m. This level corresponds to 22.1 mCi km^{-2} and from our ^{137}Cs determinations in 1978 we would have expected: $\frac{92.5}{1.6}$ = 57.8 mCi ^{90}Sr km^{-2} where 1.6 is the $^{137}Cs/^{90}Sr$ ratio in fallout. It is well known that the soil at St. Jyndevad is very sandy and this may explain the deep penetration of ^{90}Sr at this location.

Table 4.5. Strontium-90 in soil samples collected in June 1978 at St. Jyndevad

Depth in cm	A_1		A_2	
	Bq kg^{-1}	Bq m^{-2} cm^{-1}	Bq kg^{-1}	Bq m^{-2} cm^{-1}
2.5	1.63	21	1.34 ±0.06	15.8±0.6
5	0.93	21	0.96 ±0.04	18.6±0.8
10	0.99	16.6	1.00 ±0.06	19.2±1.2
15	1.11	20	0.96 ±0.06	18.6±1.1
20	0.93	20	0.86 ±0.02	16.2±0.4
25	0.72	14.8	0.70 ±0.01	12.4±0.2
30	0.30	5.6	0.53 ±0.07	11.8±1.6
40	0.25	4.8	0.23 ±0.03	4.1±0.5
50	0.20	3.8	0.172±0.009	3.8±0.2
65	0.21	3.9	0.181±0.011	3.6±0.2
80	0.132	2.1	0.156±0.007	3.6±0.2
100	0.170	3.0	0.172±0.009	3.8±0.2

4.6. Sediments

4.6.1. Strontium-90 in sediments collected at Barsebäck and Ringhals in 1979

In order to determine the amount of fallout ^{90}Sr present in sediments from inner Danish waters, we analysed the contents in two sediment cores collected in 1979 from location 48 at Barsebäck (cf. fig. 3.2.1.3) and location 2 at Ringhals (cf. fig. 3.2.1.2). As expected[21)], the ^{90}Sr levels were low in marine sediments: only 1-2% of the ^{137}Cs content (cf. Risø-R-421 p. 39 and p. 41). Hence we may disregard ^{90}Sr in marine sediments.

Table 4.6.1. Strontium-90 in sediments samples (depth: 0-9 cm) collected at Barsebäck and Ringhals in 1979

Location		Date	Bq kg^{-1}	Bq m^{-2}
Barsebäck*	48	7/4-1979	0.130	5.7
Ringhals**	2	11/5-1979	0.126	11.2

* Cf. Fig. 3.2.1.

**Cf. Fig. 3.2.2.

4.6.2. Cesium-137 in sediments collected in Roskilde Fjord

As a part of the environmental control around Risø National Laboratory, sediments are collected in Roskilde Fjord (cf. fig. 4.6.2). The highest ^{137}Cs concentrations as well as the highest depositions were found at location X: 820 Bq m^{-2} (22 nCi m^{-2}). The other five locations showed nearly the same deposition: 494±43 Bq m^{-2} (1 S.D.). At stations I, III and IX: 50±5% of the total ^{137}Cs were in the 0-3 cm layer; at the other 3 locations: IV, V and X this layer contained only 28±5% of the total ^{137}Cs suggesting a more rapid sedimentation rate or a greater biotubation at these 3 locations than at the others.

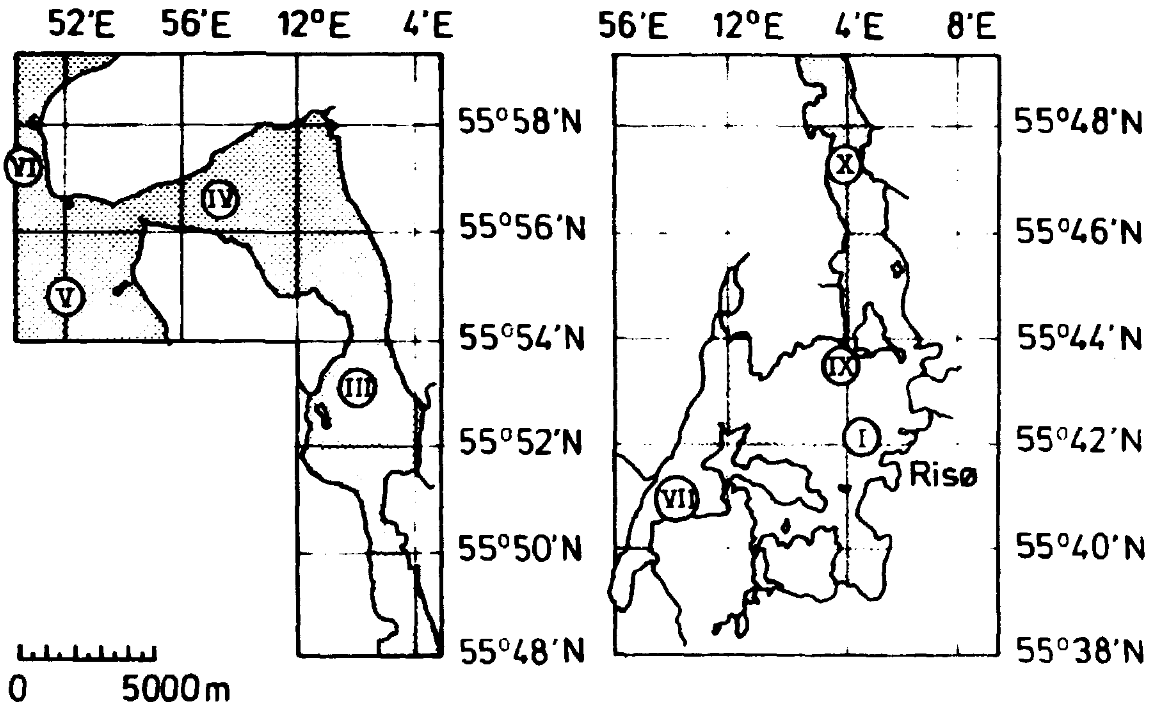

Fig. 4.6.2. Roskilde fjord.

The Kd value for ^{137}Cs in Roskilde Fjord sediments becomes 10^3 (Bq kg^{-1} surface (0-3 cm) sediments/Bq l^{-1} sea water) (cf. Table 4.4.6).

Table 4.6.2.1. Cesium-137 in sediment samples collected in Roskilde fjord, July 25, 1980. (Unit: Bq kg^{-1} dry) (HAPS) (Area 0.0145 m^2)

Depth in cm	I	III	IV	V	IX	X
0-3	26	27	13.4	11.0	36	38
3-6	15.2	15.0	9.8	5.4	18.8	42
6-9	4.8	6.6	4.6	2.4	4.6	32
9-12	1.19	2.7	2.3	2.5	2.6	13.2
12-15		1.2 A	1.72	1.95	0.9 A	5.2
15-18			1.06 A		0.8* B	3.5

*15-17 cm

Table 4.6.2.2. Cesium-137 in sediment samples collected in Roskilde fjord, July 25, 1980. (Unit: Bq m^{-2}) (HAPS) (Area 0.0145 m^2)

Depth in cm	I	III	IV	V	IX	X
0-3	300	250	128	145	220	191
3-6	172	160	177	115	166	300
6-9	55	52	98	64	58	200
9-12	18.4	17.5	47	66	33	82
12-15		9.2 A	31	43	12.6 A	27
15-18			19.6 A		6.8* B	18.9
Σ	550	490	500	430	500	820

*15-17 cm

5. DANISH FOOD AND VARIOUS VEGETATION

by A. Aarkrog

5.1. Strontium-90 and Cesium-137 in dried milk from the entire country

As in previous years, monthly samples of dried milk were collected from seven locations in Denmark (cf. fig. 5.1.1). Table

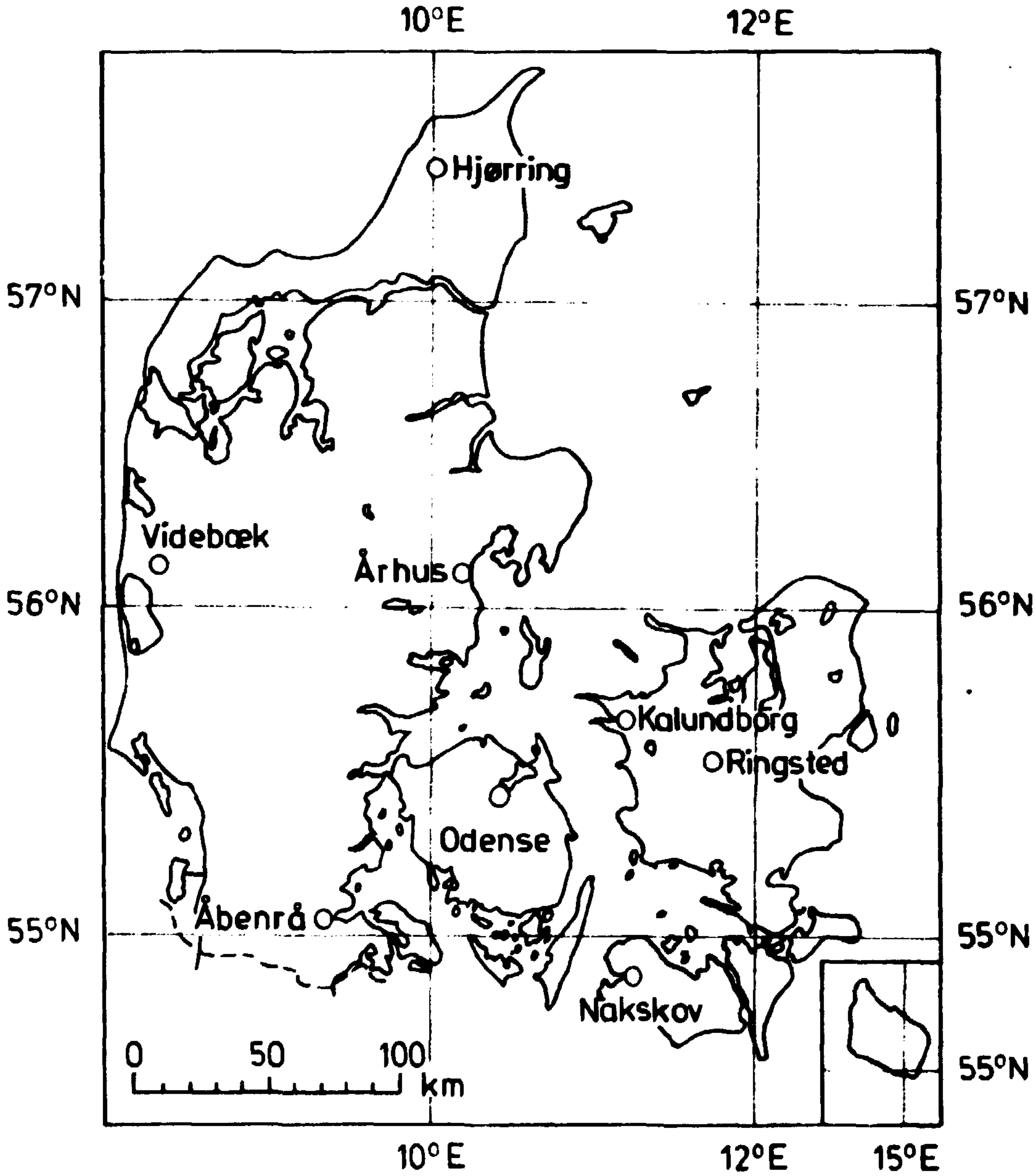

Fig. 5.1.1. Dried milk factories in Denmark.

5.1.1 shows the results of the ^{90}Sr determinations and Table 5.1.2 the analysis of variance of the results. As in recent years, the time variation was significant for Bq ^{90}Sr (kg Ca)$^{-1}$; the levels in the second quarter of the year were the highest. The Bq ^{90}Sr (kg Ca)$^{-1}$ mean level in 1980 was 106 Bq ^{90}Sr (kg Ca)$^{-1}$, i.e. the same as the 1979 mean.

Table 5.1.1. Strontium-90 in Danish dried milk in 1980. (Unit: Bq (kg Ca)$^{-1}$)

Month	Hjørring	Århus	Videbæk	Åbenrå	Odense	Ringsted	Lolland-Falster Møn	Mean
Jan	138	125	111±3	113	82±7	81	77	104
Feb	118	114	135	112	78±11	87	67	102
March	107	107±1	128	145	72	82±10	60	100
April	112	94±8	132	144	64	81	64	99
May	127	95	152	115	(89)	90	99	110
June	123	117	153	153	(84)	76	61±1	109
July	143	109	126	160	(84)	72	60	108
Aug	126	103	105	125	84	76	67	98
Sept	132	101	133	104	(78)	59	78	98
Oct	146	135	142	166	96	95	77	123
Nov	119	(120)	119	159	101	(87)	85	113
Dec	95	(117)	158	134	116	79	79	111
Mean	124	111	133	136	86	80	73	106
Mean pCi (g Ca)$^{-1}$	3.4	3.0	3.6	3.7	2.3	2.2	2.0	2.9

As 1 cubic meter of milk contains 1.2 kg Ca, the mean ^{90}Sr content in Danish milk produced in 1980 was 127 Bq m^{-3} (3.4 pCi l^{-1}). Figures in brackets calculated from VAR3[12]. The error term is 1 S.E. of the mean of double determinations.

Table 5.1.2. Analysis of variance of ln Bq ^{90}Sr (kg Ca)$^{-1}$ in Danish dried milk in 1980 (from Table 5.1.1)

Variation	SSD	f	s^2	v^2	P
Between months	0.387	11	0.035	1.805	-
Between locations	4.892	6	0.815	41.790	> 99.95%
Months × locations	1.151	59	0.020	1.359	-
Remainder	0.101	7	0.014		

As previously, milk from eastern Denmark showed significantly lower levels than that from Jutland.

Table 5.1.3 shows the results of the ^{137}Cs determinations and Table 5.1.4 the analysis of variance of the results. The ^{137}Cs mean level in 1980 was 67 Bq ^{137}Cs (kg K)$^{-1}$, or 0.6 times the 1979 level.

Table 5.1.3. Cesium-137 in Danish dried milk in 1980. (Unit: Bq (kg K)$^{-1}$)

Month	Hjørring	Århus	Videbæk	Åbenrå	Odense	Ringsted	Lolland-Falster Møn	Mean
Jan	77 A	97	101	55	39 A	40 A	35	63
Feb	107	92	89	73	53 A	33 A	37	69
March	85 A	84	78 A	76	71	47 A	37	68
April	84	72	96	75	39	33	45	64
May	85	70	76	61	(40)	33	38	58
June	134	106	117	92	(59)	47	49	86
July	112	100	122	110	(54)	34	39	82
Aug	111	85	138	134	50	43	34	85
Sept	87	158	106	121	(53)	31 A	34	84
Oct, Nov, Dec	63	63	73	62	31	27	26	49
Mean*	89	88	95	82	46	35	36	67
Mean* Bq (kg K)$^{-1}$	2.4	2.4	2.6	2.2	1.24	0.95	0.97	1.81

As 1 cubic meter contains approx. 1.66 kg K, the mean content in Danish milk produced in 1980 was estimated at 111 Bq m^{-3} (3.0 nCi l^{-1}). Figures in brackets were calculated from VAR3[12].

*Weighted mean.

Table 5.1.4. Analysis of variance of ln Bq ^{137}Cs (kg K)$^{-1}$ in Danish dried milk in 1980 (from Table 5.1.3)

Variation	SSD	f	s^2	v^2	P
Between months	2.959	11	0.269	10.470	> 99.95%
Between locations	14.077	6	2.346	91.331	> 99.95%
Remainder	1.593	62	0.026		

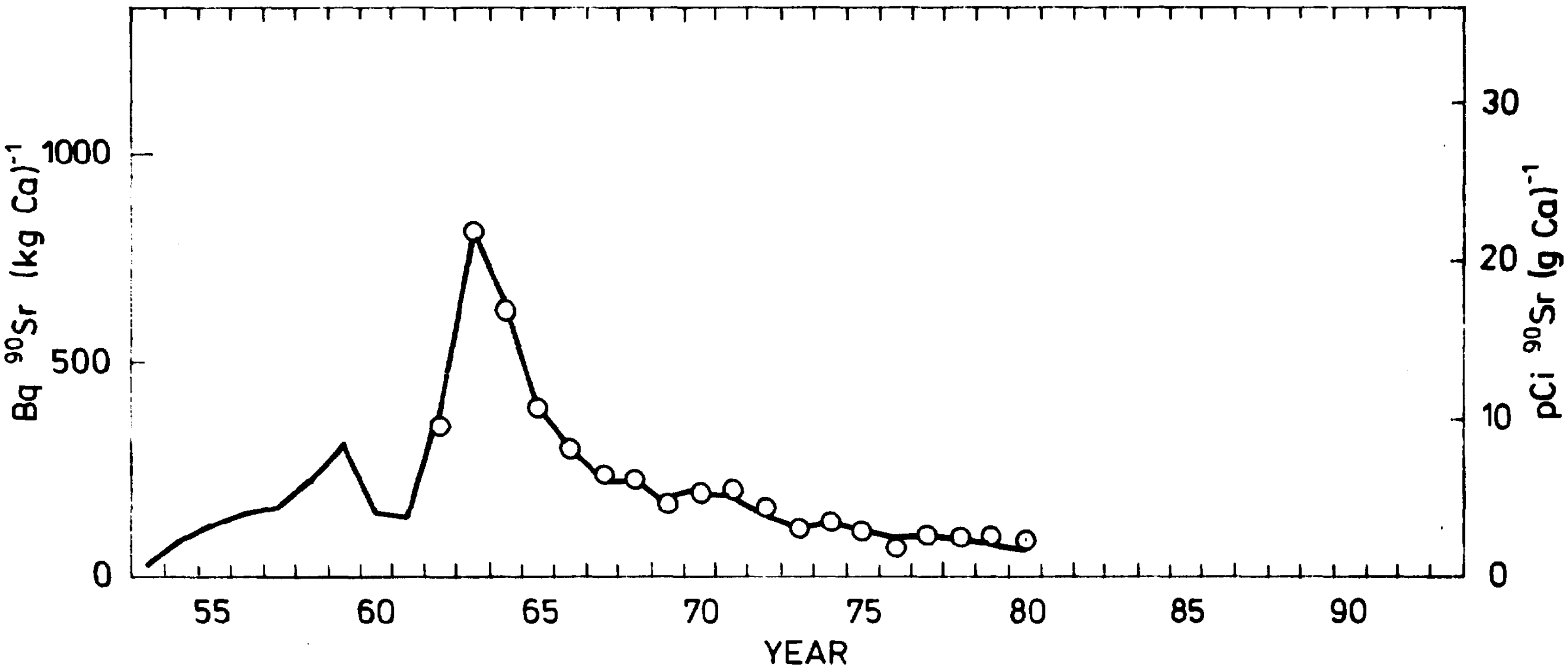

Fig. 5.1.2. Predicted (curve) and observed $^{90}Sr/Ca$ levels in dried milk from the Islands (May 1962-April 1981).

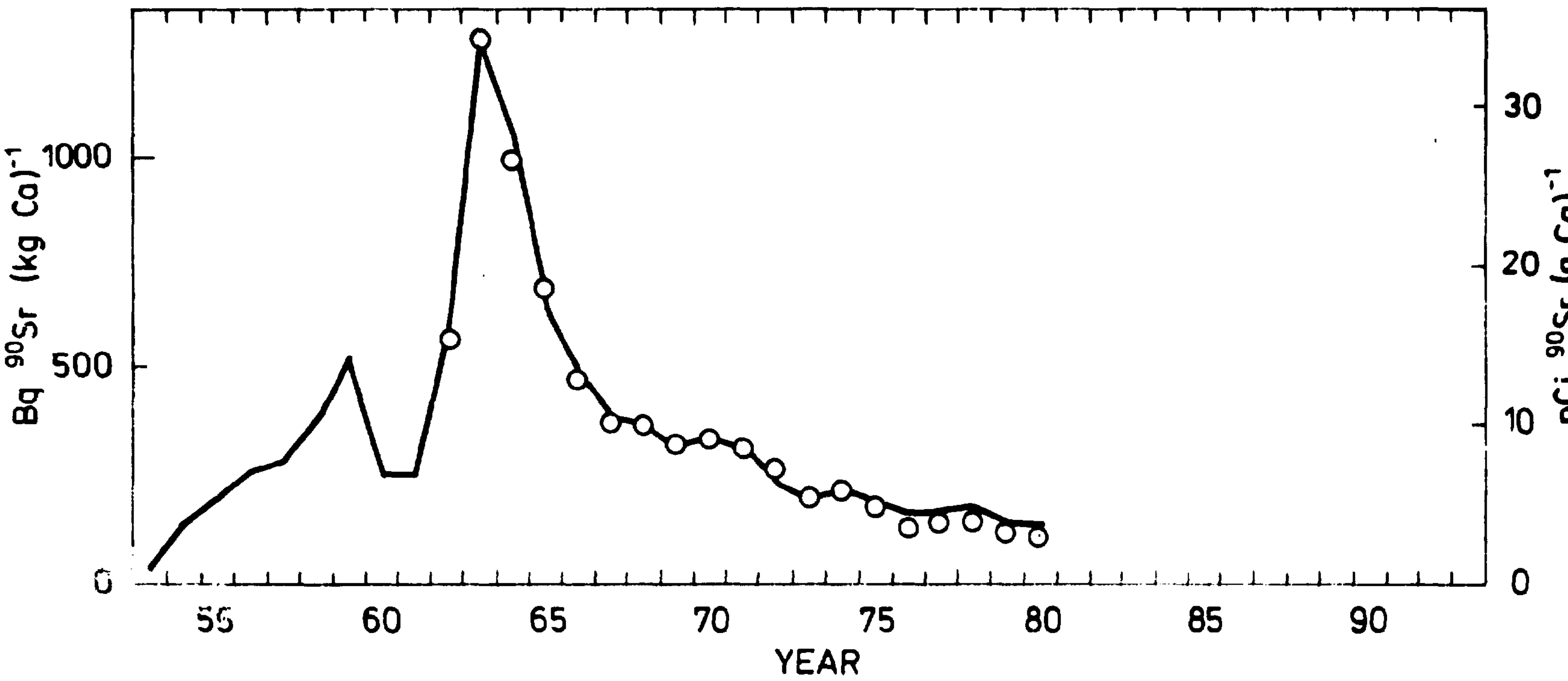

Fig. 5.1.3. Predicted (curve) and observed ^{90}Sr/Ca levels in dried milk from Jutland (May 1962-April 1981).

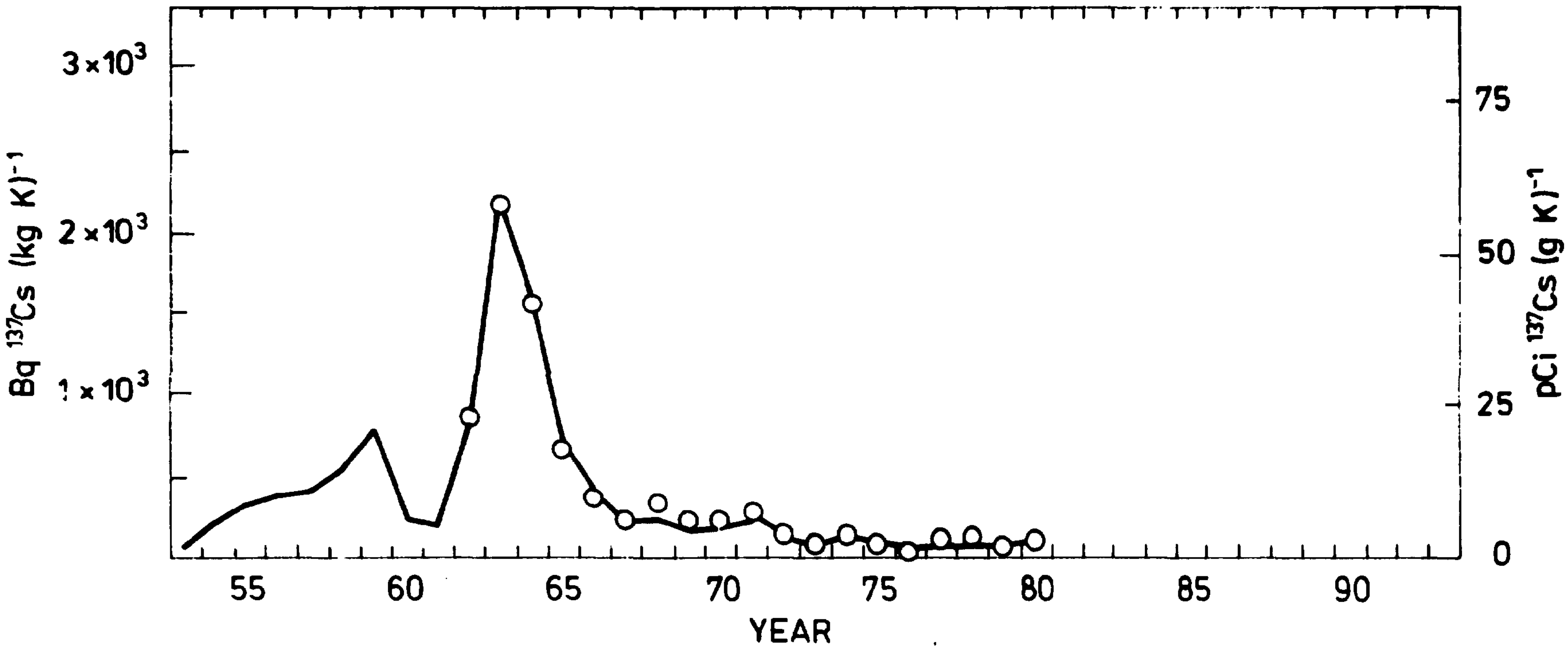

Fig. 5.1.4. Predicted (curve) and observed $^{137}Cs/K$ levels in dried milk from the Islands (May 1962–April 1981).

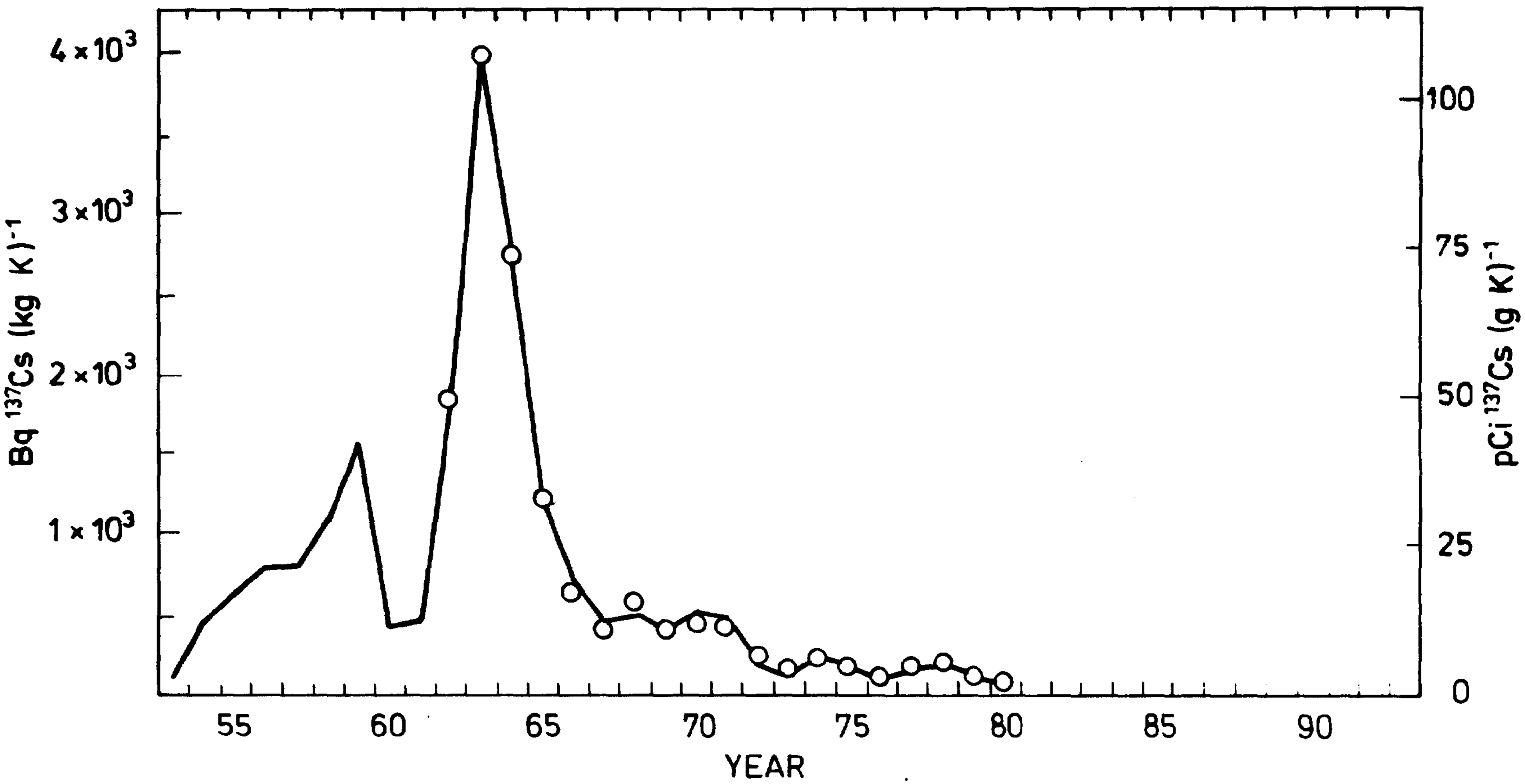

Fig. 5.1.5. Predicted (curve) and observed ^{137}Cs/K levels in dried milk from Jutland (May 1962-April 1981).

Figures 5.1.2-5.1.5 show the ^{90}Sr and ^{137}Cs levels in dried milk compared with the predicted values (cf. Appendix C). The observed ^{90}Sr levels in 1980 were 1.12 times the predicted, while the observed ^{137}Cs levels were 1.00 times the predicted ones (means of Jutland and the Islands).

5.2. Fresh milk

No samples in 1980.

5.3. Strontium-90 and Cesium-137 in grain from the entire country

As in previous years, grain samples were obtained from the State experimental farms (cf. fig. 4.2). Strontium-90 was determined as previously (Risø Report No. 63[1]), and ^{137}Cs was measured on ashed samples by γ-spectrometry on a Ge(Li) detector.

Tables 5.3.1 and 5.3.2 show the measurements of ^{90}Sr in grain in 1980. According to Appendix B, approximately 2/3 of all rye in Denmark is grown in Jutland and 1/3 in the eastern part of the country. As regards wheat, 4/5 is produced in eastern Denmark and 1/5 in Jutland. In the calculation of the means in Tables 5.3.1 and 5.3.2 and in Tables 5.3.5 and 5.3.6 Jutland is represented by four rye samples and six wheat samples, while eastern Denmark contributes nine wheat and three rye samples. Thus the means in Table 5.3.1 for wheat are higher than the production-weighted means for the country while the mean for rye is lower because the levels in Jutland are higher than those in East Denmark. Table 5.3.4 gives the analysis of variance of the Bq ^{90}Sr (kg Ca)$^{-1}$ figures and Table 5.3.3 that of the Bq ^{90}Sr kg^{-1} grain figures.

Table 5.3.4 shows that the variations in Bq ^{90}Sr (kg Ca)$^{-1}$ between species and locations were significant. Oats showed the lowest Bq ^{90}Sr (kg Ca)$^{-1}$ levels. The Bq ^{90}Sr kg^{-1} figures did not show any significant difference between species (cf. Table 5.3.3).

Table 5.3.1. Strontium-90 in Danish grain in 1980. (Unit: Bq kg^{-1})

	Rye Winter	Barley		Wheat		Oats Spring
		Spring	Winter	Winter	Spring	
Tylstrup	0.70	1.24	1.07	1.18		1.24
Ødum		0.65	0.48	0.72		0.72
Askov	0.68	1.55	0.73	1.37		1.32
Borris	1.28	1.38	1.02	1.72	0.57	1.02
St. Jyndevad	1.35	1.44	0.59	1.77		
Funen		0.64		0.54		0.83
Tystofte	0.30	0.80	0.50	0.46	0.92	0.88
Ledreborg	0.54	0.73	0.68	0.72	0.93	0.97
Abed		0.57		0.52	0.42	0.62
Rønne	0.32	0.70	1.08	0.38	0.26	0.66
Mean Bq kg^{-1}	Rye: 0.74	Barley: 0.88		Wheat: 0.83		Oats: 0.92
Mean pCi kg^{-1}	Rye: 20	Barley: 24		Wheat: 22		Oats: 25

Table 5.3.2. Strontium-90 in Danish grain in 1980. (Unit: Bq $(kg\ Ca)^{-1}$)

	Rye Winter	Barley		Wheat		Oats Spring
		Spring	Winter	Winter	Spring	
Tylstrup	2600	3600	2000	3400		1690
Ødum		1340	1160	1700		820
Askov	2700	2400	2000	2700		1810
Borris	1810	3300	4200	4400	1740	2700
St. Jyndevad	3400	3800	1730	4400		
Funen		1000		1530		1030
Tystofte	1090	1750	1310	1580	1760	1120
Ledreborg	1320	1400	1730	2000	1980	970
Abed		1120		1700	920	720
Rønne	1060	1020	1950	1180	730	740
Mean Bq $(kg\ Ca)^{-1}$	Rye: 2000	Barley: 2050		Wheat: 2100		Oats: 1290
Mean pCi $(g\ Ca)^{-1}$	Rye: 54	Barley: 55		Wheat: 57		Oats: 35

Table 5.3.3. Analysis of variance of ln Bq ^{90}Sr kg^{-1} in grain in 1980 (from Table 5.3.1)

Variation	SSD	f	s^2	v^2	P
Between species	1.026	3	0.342	3.526	> 95%
Between locations	5.301	9	0.589	6.075	> 99.95%
Spec. × loc.	2.230	23	0.097	0.642	-
Remainder	1.963	13	0.151		

Table 5.3.4. Analysis of variance of ln Bq ^{90}Sr $(kg\ Ca)^{-1}$ in grain in 1980 (from Table 5.3.2)

Variation	SSD	f	s^2	v^2	P
Between species	1.236	3	0.412	8.090	> 99.9%
Between locations	7.505	9	0.834	16.378	> 99.95%
Spec. × loc.	1.171	23	0.051	0.433	-
Remainder	1.529	13	0.118		

As in previous years, the variation with location was highly significant; the mean pCi ^{90}Sr kg^{-1} level for grain from Jutland was 1.7 times that in eastern Denmark. The observed pCi ^{90}Sr kg^{-1} levels in grain from 1980 were 1.58±0.51 (1 S.D.) times those predicted (cf. Appendix C).

Tables 5.3.5 and 5.3.6 show the measurements of ^{137}Cs in grain in 1980. The ^{137}Cs mean level in grain from 1980 was 0.76 times the level in 1979. The fallout in May-August 1980 was 0.73 times that of the fallout in May-August 1979.

The ANOVA's (Tables 5.3.7 and 5.3.8) showed significant variation between species (rye > the other species) and between locations (Jutland = 1.54 × The Islands).

The observed pCi ^{137}Cs kg^{-1} levels in grain from 1980 were 1.30± 0.28 (1 S.D.) times those predicted (cf. Appendix C).

Table 5.3.5. Cesium-137 in Danish grain in 1980. (Unit: Bq kg^{-1})

	Rye Winter	Barley Spring	Barley Winter	Wheat Winter	Wheat Spring	Oats Spring
Tylstrup	0.25	0.188	0.35	0.24		0.22
Ødum		0.197	0.25	0.29		0.26
Askov	0.39	0.48	0.30	0.44		0.70
Borris	0.33	0.32	0.30	0.25	0.41	0.30
St. Jyndevad	0.50	0.23	0.38	0.29		
Funen		0.24		0.24		0.37
Tystofte	0.24	0.175	0.154	0.120	0.137 A	0.21
Ledreborg	0.34	0.24	0.26	0.174	0.181	0.25
Abed		0.198		0.177	0.20	0.144
Rønne	0.28	0.31	0.191	0.175	0.138	0.164
Mean Bq kg^{-1}	Rye: 0.33	Barley: 0.26		Wheat: 0.23		Oats: 0.29
Mean pCi kg^{-1}	Rye: 8.9	Barley: 7.0		Wheat: 6.2		Oats: 7.8

Table 5.3.6. Cesium-137 in Danish grain in 1980. (Unit: Bq $(kg\ K)^{-1}$)

	Rye Winter	Barley Spring	Barley Winter	Wheat Winter	Wheat Spring	Oats Spring
Tylstrup	63	35	64	50		51
Ødum		44	66	58		56
Askov	96	121	78	100		152
Borris	82	77	68	61	98	87
St. Jyndevad	87	56	81	67		
Funen		51		55		89
Tystofte	53	36	47	36	29	58
Ledreborg	76	52	66	40	46	60
Abed		48		43	49	41
Rønne	55	44	31	40	37	40
Mean Bq $(kg\ K)^{-1}$	Rye: 73	Barley: 59		Wheat: 54		Oats: 71
Mean pCi $(g\ K)^{-1}$	Rye: 1.97	Barley: 1.60		Wheat: 1.46		Oats: 1.91

Table 5.3.7. Analysis of variance of ln Bq ^{137}Cs kg^{-1} in grain in 1980 (from Table 5.3.5)

Variation	SSD	f	s^2	v^2	P
Between species	0.506	3	0.169	3.155	> 95%
Between locations	3.782	9	0.420	7.865	> 99.95%
Spec. × loc.	1.229	23	0.053	0.927	-
Remainder	0.749	13	0.053		

Table 5.3.8. Analysis of variance of ln Bq ^{137}Cs $(kg\ K)^{-1}$ in grain in 1980 (from Table 5.3.6)

Variation	SSD	f	s^2	v^2	P
Between species	0.512	3	0.171	6.352	> 99.5%
Between locations	4.133	9	0.459	17.077	> 99.95%
Spec. × loc.	0.619	23	0.027	0.487	-
Remainder	0.717	13	0.055		

5.4. Strontium-90 and Cesium-137 in bread from the entire country

In 1980, samples of white bread (75% extraction) and dark rye bread (100% extraction) were collected all over the country (cf. fig. 5.4) in June, and ^{90}Sr and ^{137}Cs were determined on pooled samples except ^{137}Cs in rye bread, which was determined on each zone separately. The ^{137}Cs determinations were carried out on the ash by Ge γ-spectroscopy.

Table 5.4.1 shows the results. It is assumed that 1 kg flour yields approximately 1.35 kg bread[11] and that wheat flour of 75% extraction contains 20% of the ^{90}Sr and 50% of the ^{137}Cs found in wheat grain[1], while rye flour is 100% extraction. Hence we can compare the 1980 bread levels with the 1979 grain levels (cf. Table 5.4.2). The above assumptions for transfer of ^{137}Cs from grain to bread seem justified, however, the transfer of ^{90}Sr from wheat to white bread may be underestimated. This has in fact been envisaged in Risø-R-437 p. 86[21] where it is predicted that the transfer will increase from 20 to 33%.

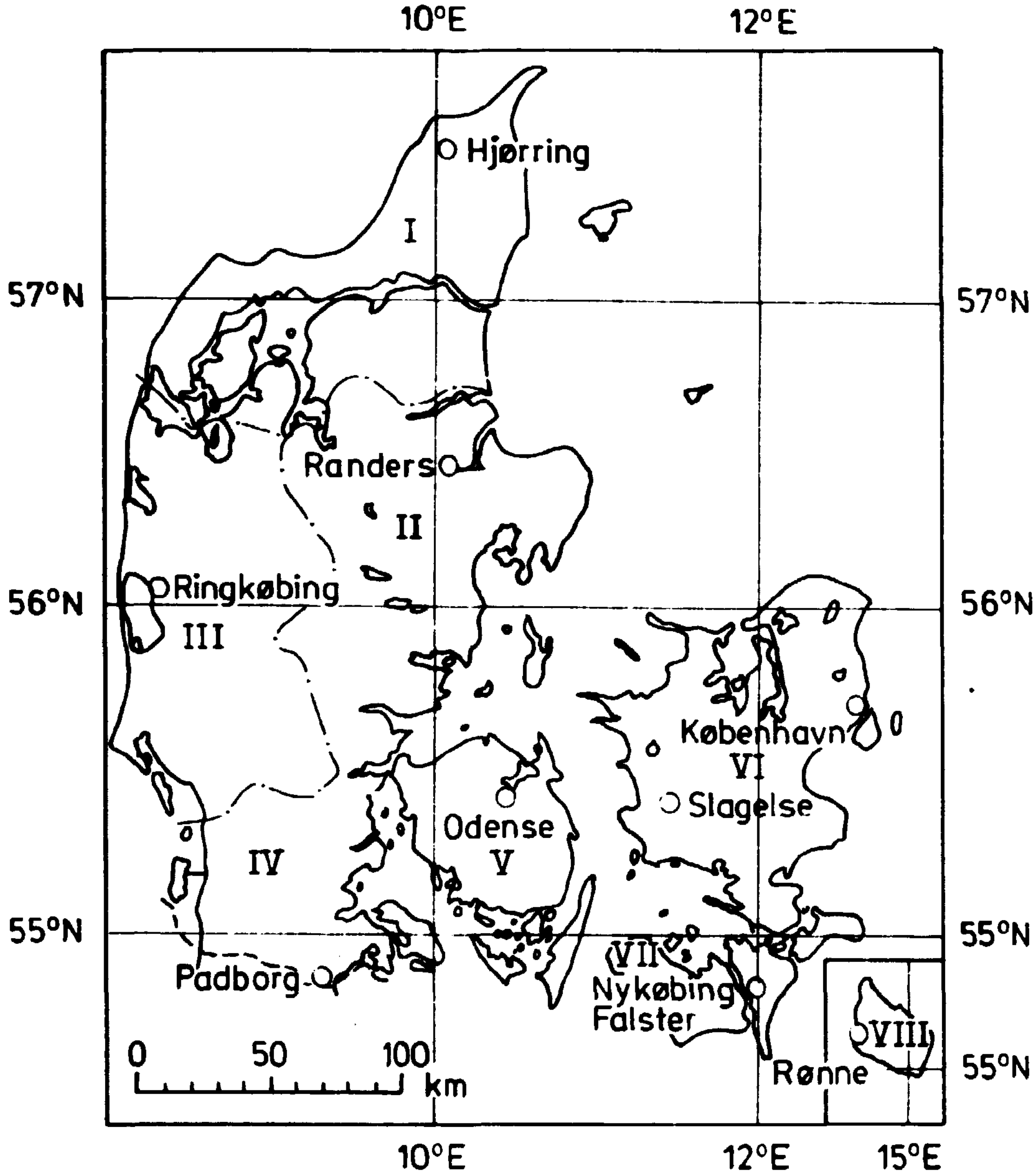

Fig. 5.4. Sample locations for bread and total diet.

Table 5.4.1. Strontium-90 and Cesium-137 in Danish bread collected in June 1980

Zone	Rye bread				White bread			
	Bq ^{90}Sr kg^{-1}	Bq ^{90}Sr (kg Ca)$^{-1}$	Bq ^{137}Cs kg^{-1}	Bq ^{137}Cs (kg K)$^{-1}$	Bq ^{90}Sr kg^{-1}	Bq ^{90}Sr (kg Ca)$^{-1}$	Bq ^{137}Cs kg^{-1}	Bq ^{137}Cs (kg K)$^{-1}$
I: N. Jutland			0.50	147				
II: E. Jutland	0.70	230	0.33	115	0.161	82	0.121	77
III: W. Jutland			0.42	124				
IV: S. Jutland			0.27	90				
V: Funen			0.27	83				
VI: Zealand	0.61	183	0.31	103	0.157	75	0.079	59
VII: Lolland-Falster			0.34	107				
VIII: Bornholm			0.24	62				
Mean	0.66	210	0.33	104	0.159	78	0.100	68
Mean	17.7 pCi kg^{-1}	5.6 pCi (g Ca)$^{-1}$	9.0 pCi kg^{-1}	2.8 pCi (g K)$^{-1}$	4.3 pCi kg^{-1}	2.1 pCi (g Ca)$^{-1}$	2.7 pCi kg^{-1}	1.84 pCi (g K)$^{-1}$
Copenhagen	0.62	260	0.38	112	0.105	57	0.085	58
Population-weighted mean	0.66	230	0.36	112	0.145	74	0.100	67

Table 5.4.2. A comparison between ^{90}Sr and ^{137}Cs levels in bread and grain 1980

Nuclide	Species	Bread activity in June 1980 calculated as gr 'n in Bq kg^{-1} (cf. text)	Activity in grain from harvest 1979[1)] Bq kg^{-1}	"Bread"/grain ratio
^{90}Sr	Wheat	1.07	0.72	1.5
	Rye	0.89	0.75	1.2
^{137}Cs	Wheat	0.27	0.29	0.9
	Rye	0.45	0.45	1.0

5.5. Strontium-90 and Cesium-137 in potatoes from the entire country

The samples of potatoes were collected in September from ten of the State experimental farms (cf. fig. 4.2) and analysed for ^{90}Sr and ^{137}Cs (γ-spectroscopy of bulked samples of the ash).

Table 5.5.1 shows the ^{90}Sr and ^{137}Cs contents in potatoes. The mean contents for the country were 0.084 Bq ^{90}Sr kg^{-1}, or 1730 Bq ^{90}Sr (kg Ca)$^{-1}$, and 0.077 Bq ^{137}Cs kg^{-1} or 18.5 Bq ^{137}Cs (kg K)$^{-1}$. The levels were nearly equal to those in 1979.

Table 5.5.1. Strontium-90 and Cesium-137 in Danish potatoes in 1980

	Bq ^{90}Sr kg^{-1}	Bq ^{90}Sr (kg Ca)$^{-1}$	Bq ^{137}Cs kg^{-1}	Bq ^{137}Cs (kg K)$^{-1}$
Tylstrup	0.078±0.010	2070±330		
Borris	0.096±0.005	2320± 70		
Ødum	0.123±0.013	1500± 40	0.127	31
Askov	0.181	5210		
St. Jyndevad	0.054±0.001	1750± 90		
Funen	0.110±0.001	1920± 10		
Tystofte	0.043±0.001	590± 30		
Ledreborg	0.035±0.001	650± 10	0.027	6
Abed	0.047±0.001	470± 10		
Rønne	0.061±0.002	1170± 20		
Mean	0.083	1770	0.077	18.5
Mean	2.2 pCi kg^{-1}	48 pCi (g Ca)$^{-1}$	2.1 pCi kg^{-1}	0.50 pCi (g K)$^{-1}$

The error term is 1 S.E. of the mean of double determinations.

The mean ratio between observed and predicted ^{90}Sr concentrations in potatoes was 0.77 and for ^{137}Cs we found 0.76 (cf. Appendix C).

5.6. Strontium-90 and Cesium-137 in vegetables and fruit from the entire country

In 1980, as in previous years, vegetables and fruit were collected in the autumn from eight larger provincial towns, one in each of the eight zones (cf. fig. 5.4).

The γ-measurements were performed on bulked ash samples representing the entire country (cf. Table 5.6.2).

Table 5.6.3 shows a calculation of the mean contents of ^{90}Sr and ^{137}Cs in Danish vegetables collected in 1980. The levels are the population-weighted means and are similar to those in 1979 and 1978 suggesting that most of the activity in vegetables depends upon the accumulated activity in the soil.

Table 5.6.1. Strontium-90 in vegetables and fruits collected in September 1980

	Cabbage		Carrot		Apples	
	Bq kg^{-1}	Bq (kg Ca)$^{-1}$	Bq kg^{-1}	Bq (kg Ca)$^{-1}$	Bq kg^{-1}	Bq (kg Ca)$^{-1}$
I: North Jutland	0.50	760	0.46±0.03	1960±160	0.064	1610
II: East Jutland	0.99±0.11	2620±310	0.41	850	0.060	1660
III: West Jutland	0.59±0.04	1340± 80	0.73±0.01	2880±120	0.035	960
IV: South Jutland	0.36	560	0.64	2100	0.008	120
V: Funen	0.38±0.02	570± 20	0.58±0.05	2010±270	0.018	480
VI: Zealand	0.19±0.02	440± 60	0.30±0.11	920±340	0.023	510
VII: Lolland-Falster	0.23	430	0.16	510	0.027	690
VIII: Bornholm	0.46±0.07	850±130	0.63	1390± 50	0.041	880
Mean	0.44	950	0.49	1590	0.034	860
Mean	12.0 pCi kg^{-1}	26 SU	13.2 pCi kg^{-1}	43 SU	0.93 pCi kg^{-1}	23 SU
Copenhagen	0.26±0.03	400± 60	0.27±0.01	900± 30	0.065	1090
Population-weighted mean	0.45	980	0.43	1420	0.044	1000

The error term is 1 S.E. of double determinations.

Table 5.6.2. Cesium-137 in Danish vegetables and fruits in September 1980

	Cabbage		Carrot		Apples	
	Bq kg^{-1}	Bq (kg K)$^{-1}$	Bq kg^{-1}	Bq (kg K)$^{-1}$	Bq kg^{-1}	Bq (kg K)$^{-1}$
Jutland	0.25	106	0.060	24	0.053	45
The Islands	0.020	8.8	0.040	19	0.037	30
Mean	0.134	58	0.050	22	0.045	38
Mean	3.6 pCi kg^{-1}	1.6 M.U.	1.35 pCi kg^{-1}	0.6 M.U.	1.2 pCi kg^{-1}	1.0 M.U.
Population-weighted mean	0.124	53	0.049	21	0.044	37

Table 5.6.3. Calculated ^{90}Sr and ^{137}Cs mean levels in vegetables in 1980

Daily intake in g	Bq ^{90}Sr kg^{-1}	Bq ^{90}Sr $(kg\ Ca)^{-1}$	Bq ^{137}Cs kg^{-1}	Bq ^{137}Cs $(kg\ K)^{-1}$
50 leaf vegetables (cabbage)	0.45	980	0.124	53
30 root vegetables (carrot)	0.43	1420	0.049	21
40 pea (1977 data)	0.13	440	0.059	4
120	0.34	910	0.084	29

The 1979 levels in Danish fruit were calculated from apples and the mean levels in Danish fruit were thus 0.044 Bq ^{90}Sr kg^{-1} and 0.044 Bq ^{137}Cs kg^{-1}. The observed Bq ^{90}Sr kg^{-1} levels in vegetables and fruit in 1980 were 1.46±0.46 (1 S.D.) times those predicted (cf. Appendix C). In the case of ^{137}Cs, the observed values were 1.42 times the predicted ones.

5.7. Strontium-90 and Cesium-137 in total diet from the entire country

In 1980 total-food samples representing an average Danish diet according to E. Hoff-Jørgensen (cf. Appendix B in Risø Report No. 63[1])) were collected from eight towns each representing one of the eight zones (cf. fig. 5.2.1) and from Copenhagen. The sampling took place as previously in June and December.

Tables 5.7.1 and 5.7.2 show the results. The diet levels from Jutland were 29% higher than those from the Islands.

Figure 5.7.1 show the zone mean Bq ^{90}Sr $(kg\ Ca)^{-1}$ levels (not population-weighted) in total diet compared with the predicted values (cf. Appendix C), the observed value was 0.92 times that predicted.

The ^{90}Sr 1980 levels (June and December values) in the total diet were nearly equal to the 1979 levels, and the ^{137}Cs levels were approximately 18% lower.

Table 5.7.1. Strontium-90 and Cesium-137 in Danish total diet collected in June 1980

Zone	Bq ^{90}Sr (kg Ca)$^{-1}$	Bq ^{90}Sr d^{-1}	g Ca d^{-1}	Bq ^{137}Cs (kg K)$^{-1}$	Bq ^{137}Cs d^{-1}
I: N. Jutland	230± 7	0.37±0.01	1.61	97	0.37
II: E. Jutland	217±13	0.36±0.02	1.64	90	0.32
III: W. Jutland	165±10	0.27±0.02	1.62	101	0.38
IV: S. Jutland	145±13	0.24±0.03	1.69	73	0.28
V: Funen	179± 5	0.28±0.01	1.57	77	0.28
VI: Zealand	122± 2	0.22±0.01	1.82	120	0.47
VII: Lolland-Falster	113± 3	0.21±0.00	1.81	62	0.25
VIII: Bornholm	156± 5	0.25±0.01	1.62	58	0.22
Mean	166	0.28	1.67	85	0.32
Mean	4.48 S.U.	7.4 pCi d^{-1}		2.3 M.U.	8.7 pCi d^{-1}
Copenhagen	155∓ 1	0.26±0.02	1.65	80	0.32
Population-weighted mean	170	0.28	1.67	92	0.35
Relative error due to analysis	7%	9%			

The error term is 1 S.E. of the mean of double determinations.

Table 5.7.2. Strontium-90 and Cesium-137 in Danish total diet collected in December 1980

Zone	Bq ^{90}Sr (kg Ca)$^{-1}$	Bq ^{90}Sr d^{-1}	g Ca d^{-1}	Bq ^{137}Cs (kg K)$^{-1}$	Bq ^{137}Cs d^{-1}
I: N. Jutland	167±2	0.26±0.01	1.54	74	0.27
II: E. Jutland	158±8	0.22±0.01	1.42	77	0.29
III: W. Jutland	162±2	0.27±0.01	1.66	92	0.34
IV: S. Jutland	158±8	0.27±0.01	1.70	84	0.32
V: Funen	126±6	0.22±0.02	1.67	65	0.24
VI: Zealand	124±2	0.20±0.00	1.62	74	0.28
VII: Lolland-Falster	129±5	0.23±0.00	1.77	70	0.27
VIII: Bornholm	137±5	0.22±0.02	1.62	70	0.26
Mean	145	0.24	1.62	76	0.28
Mean	3.92 S.U.	6.4 pCi d^{-1}		2.05 M.U.	7.6 pCi d^{-1}
Copenhagen	153±3	0.26±0.00	1.72	101	0.37
Population-weighted mean	149	0.24	1.63	84	0.31
Relative error due to analysis	5%	7%			

The error term is 1 S.E. of the mean of double determinations.

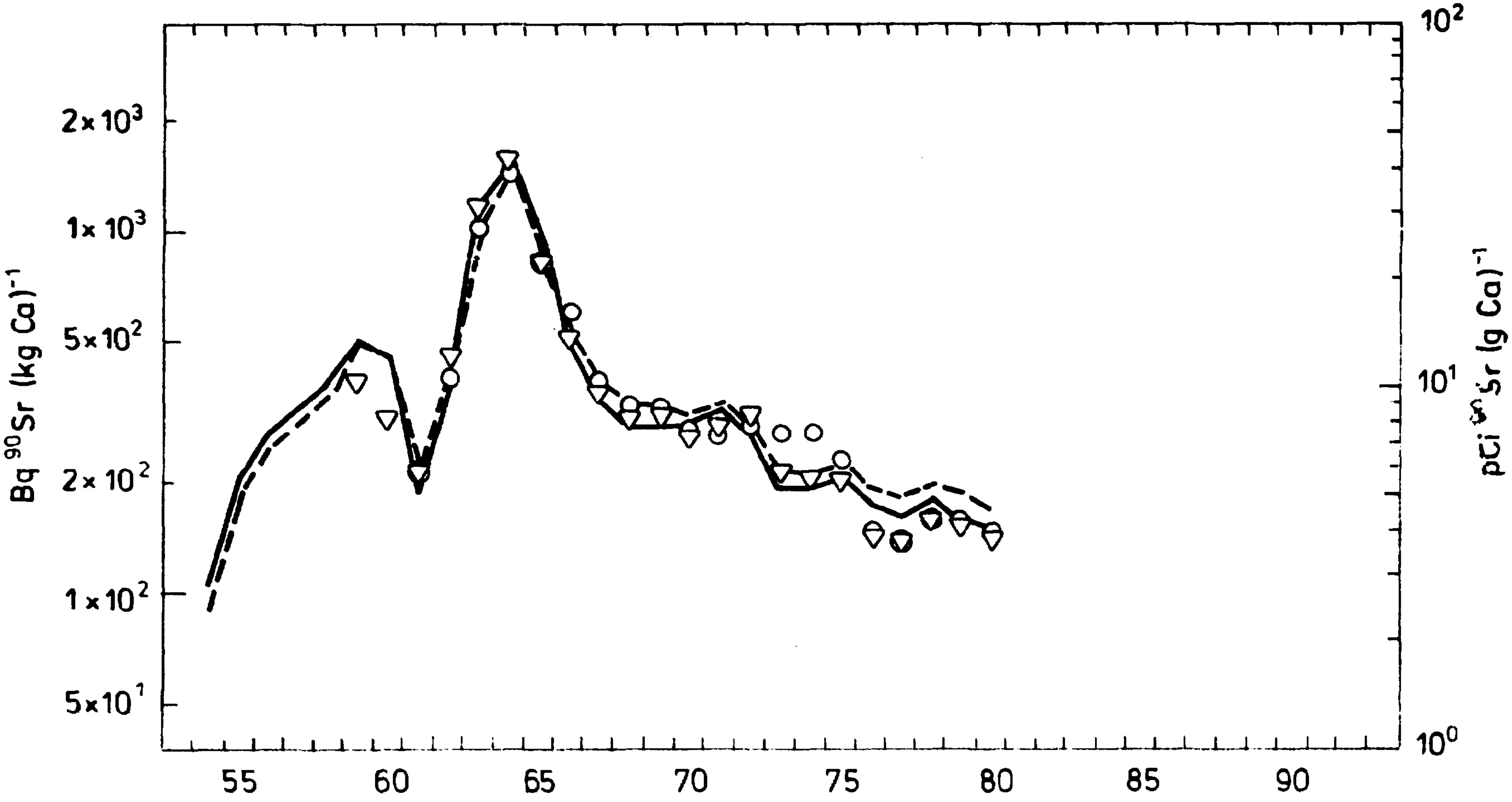

Fig. 5.7.1. Predicted and observed ^{90}Sr levels in the Danish total diet. The dotted curve represents the predicted values for "Diet C" (cf. Tables 5.7.1 and 5.7.2) and the circles are the corresponding observed values. The unbroken curve represents the predicted values for "Diet P" (cf. Table 5.9.3), and the triangles the corresponding observed values.

From the total-diet sampling it is possible to estimate the mean levels of ^{90}Sr and ^{137}Cs in the Danish diet in 1980. For the period January-March 1980, the ^{90}Sr level in the total diet is assumed to have been equal to that measured in December 1979, Risø Report No. 421[1]. For the period April-September we assume the level to have corresponded to that measured in June 1980. The December 1980 figures are taken to represent the last three months of the year. Hence the mean content in the total diet in 1980 was 157 Bq ^{90}Sr (kg Ca)$^{-1}$, or 0.26 Bq ^{90}Sr (day)$^{-1}$.

Similarly, the ^{137}Cs content in the Danish diet in 1980 was estimated to be 0.37 Bq ^{137}Cs (day)$^{-1}$ or 91 Bq ^{137}Cs (kg K)$^{-1}$. The observed ^{137}Cs fallout level in total diet was 1.20 times that predicted (cf. Appendix C.2) (corrected for ^{137}Cs from Windscale cf. 5.8.2).

5.8. Strontium-90 and Cesium-137 in miscellaneous foodstuffs

5.8.1. Strontium-90 and Cesium-137 in meat

Pork and beef samples were collected in Copenhagen in three large shops in March and September. Table 5.8.1 shows the results. As compared with 1979, the mean ^{137}Cs levels were a little lower in 1980.

The mean ratio between observed and predicted (cf. Appendix C.2) ^{137}Cs levels in meat was 1.36. As observed values we used those from September 1980 and March 1981, as the meat models cover the period April$_{(i)}$-March$_{(i+1)}$.

Table 5.8.1. Strontium-90 and Cesium-137 in Danish meat collected in Copenhagen in 1980

	Pork				Beef			
Month	Bq ^{90}Sr kg^{-1}	Bq ^{90}Sr (kg Ca)$^{-1}$	Bq ^{137}Cs kg^{-1}	Bq ^{137}Cs (kg K)$^{-1}$	Bq ^{90}Sr kg^{-1}	Bq ^{90}Sr (kg Ca)$^{-1}$	Bq ^{137}Cs kg^{-1}	Bq ^{137}Cs (kg K)$^{-1}$
March	0.012	260	0.82	220	0.012	140	0.37	100
Sept	0.006	80	0.52	140	0.020	270	0.40	90
Mean	0.009	170	0.67	180	0.016	205	0.38	95
Mean	0.24 pCi kg^{-1}	4.6 S.U.	18 pCi kg^{-1}	4.9 M.U.	0.43 pCi kg^{-1}	5.5 S.U.	10.4 pCi kg^{-1}	2.6 M.U.

5.8.2. Strontium-90 and Cesium-137 in fish

Fish samples were collected in the North Sea and in inner Danish waters. Tables 5.8.2.1 and 5.8.2.2 show the results. The mean levels of the two samplings were 0.028 Bq ^{90}Sr kg^{-1} and 4.55 Bq ^{137}Cs kg^{-1} (0.75 pCi ^{90}Sr kg^{-1} and 123 pCi ^{137}Cs kg^{-1}). In the fish from the North Sea the $^{134}Cs/^{137}Cs$ mean ratio was 0.046 while it was 0.032 for fish from inner Danish waters.

Table 5.8.2.1. Strontium-90, Cesium-137 and Cesium-134 in fish meat from the North Sea purchased in Esbjerg in September 1980

Species	Bq ^{90}Sr kg^{-1}	Bq ^{90}Sr (kg Ca)$^{-1}$	Bq ^{137}Cs kg^{-1}	Bq ^{137}Cs (kg K)$^{-1}$	$^{134}Cs/^{137}Cs$
Cod	0.030	30 (27)	8.30	1870	0.044
Plaice	0.013	20 (15)	1.22	320	0.048

Bone levels are shown in brackets.

Table 5.8.2.2. Strontium-90, Cesium-137 and Cesium-134 in fish meat from inner Danish waters purchased in Hundested in September 1980

Species	Bq ^{90}Sr kg^{-1}	Bq ^{90}Sr (kg Ca)$^{-1}$	Bq ^{137}Cs kg^{-1}	Bq ^{137}Cs (kg K)$^{-1}$	$^{134}Cs/^{137}Cs$
Cod	0.055	55 (40)	4.34	960	0.017
Plaice	0.033	30 (20)	5.21	1150	0.038
Herring	0.007	20 (11)	3.66	1260	0.041

Bone levels are shown in brackets.

The ratio: $^{134}Cs/^{137}Cs$ in North Sea water was 0.047 (cf. 4.4) in 1980, i.e. the same as found in fish. From inner Danish waters the ratio: $^{134}Cs/^{137}Cs$ in fish was approximately 70% of that in fish from the North Sea, where approximately 5% of the ^{137}Cs results from fallout (Risø-R-421 p. 63-64[1])). In other words, nearly all radiocesium in water and fish from the North Sea in 1980 was of Windscale origin. In the inner Danish waters we estimate that 70% of the ^{137}Cs was due to Windscale. As most fish are caught in the North Sea our best estimate of the Windscale contribution to ^{137}Cs in Danish fish in 1980 is 90% (~ 4.1 Bq kg^{-1}).

Garpikes migrate every spring from the waters around Britain to Danish inner waters. Elis Holm (University of Lund) got the idea that garpike thus may transport ^{137}Cs from Windscale to the Baltic area more directly than other fish and therefore contain relatively more radiocesium. Table 5.8.2.3 shows that flesh of garpike had indeed a ^{137}Ce concentration four times higher than other fish. The ratios: $^{134}Cs/^{137}Cs$ were a little higher in garpike than in North Sea water. Both observations suggest a short circuit of the transport of radiocesium from Windscale to Danish waters. Table 5.8.2.3, furthermore, shows that there was no systematic difference between the radiocesium concentrations in

Table 5.8.2.3. Strontium-90, Cesium-137 and Cesium-134 in garpike caught in the Cattegat in May 1980

Sample	Date	Bq ^{90}Sr kg^{-1}	Bq ^{90}Sr $(kg\ Ca)^{-1}$	Bq ^{137}Cs kg^{-1}	Bq ^{137}Cs $(kg\ K)^{-1}$	$^{134}Cs/^{137}Cs$
Flesh	May 6			22.9	4400	0.056
Roe	"			9.6	2700	0.073
Bone (head)	"			2.5	4200	-
Bone (back)	"			2.6	3300	-
Flesh (large)	May 16			21.6	3900	0.049
Flesh (small)	"			16.9	4000	0.060
Roe	"			11.0	2900	0.055
Flesh (4 yr) (small)	May 29		bone: 13	16.8	3400	0.059
Flesh (5 yr) (large)	"	0.032	25	13.2	2900	0.047
Flesh mean ±1 S.D.				18.2±3.9	3700±600	0.054±0.006

large (5-yr-old) and small (4-yr-old) garpike*). Roe as well as bones contained apparently lower ^{137}Cs concentrations than flesh. There was a tendency for radiocesium concentrations to decline in the flesh from the beginning of May to the end of the month. This was probably due to the dilution from the stay of the garpike in the less-contaminated Danish waters. It should, furthermore, be noticed that the ^{90}Sr levels in garpike did not differ from those in other fish.

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*) The age determinations were kindly performed by Jørgen Dalskov (Danmarks Fiskeri og Havundersøgelser).

5.8.3. Strontium-90 and Cesium-137 in various animal foods

Eggs and chicken were collected in Copenhagen and Roskilde in 1980. As compared with the corresponding sampling in 1979, the levels were lower in 1980.

Table 5.8.3. Strontium-90 and Cesium-137 in eggs from Copenhagen and chickens from Roskilde in September 1980

Sample	Bq ^{90}Sr kg^{-1}	Bq ^{90}Sr $(kg\ Ca)^{-1}$	Bq ^{137}Cs kg^{-1}	Bq ^{137}Cs $(kg\ K)^{-1}$
Eggs	0.014	24	0.028	21
Chicken meat	0.006	33	0.13	54
Chicken bone	-	54	-	-

5.8.4. Strontium-90 and Cesium-137 in various vegetable foods

As compared with the corresponding sampling in 1978 the ^{90}Sr and ^{137}Cs levels in coffee and tea had decreased by 40% and approximately 10%, respectively; the ^{90}Sr levels in orange and banana were lower in 1980 by a factor of approximately two.

Table 5.8.4. Strontium-90 and Cesium-137 in imported vegetable products collected in Copenhagen in December 1980

Sample	Bq ^{90}Sr kg^{-1}	Bq ^{90}Sr $(kg\ Ca)^{-1}$	Bq ^{137}Cs kg^{-1}	Bq ^{137}Cs $(kg\ K)^{-1}$
Coffee (as drunk)	0.43	660	0.81	50
Tea (as drunk)	1.12	5200	5.0	350
Orange	0.10	300	B.D.L.	-
Banana	0.019	6200	B.D.L.	-
Rice	0.011	20	0.031	30
Hazelnuts (Danish)	0.35	530	0.38	70
Oats (Danish)	0.86	250	0.42	94

5.9. Estimate of the mean contents of ^{90}Sr and ^{137}Cs in the human diet in Denmark in 1980

5.9.1. The annual quantities

The annual quantities are calculated by multiplication of the daily quantities by 365 (as stated by E. Hoff-Jørgensen, cf. Risø Report No. 63, Table B[1]).

5.9.2. Milk and cream

The ^{90}Sr and ^{137}Cs contents per kg milk were calculated from the annual mean values for dried milk (cf. Tables 5.1.1 and 5.1.3). 1 kg ~ 1 l milk, containing approximately 1.2 g Ca and 1.66 g K. Hence the mean contents in milk were 0.127 Bq ^{90}Sr kg^{-1} and 0.111 Bq ^{137}Cs kg^{-1}.

5.9.3. Cheese

One kg of cheese contains approximately 8.5 g Ca and 1.2 g K. The ^{90}Sr and ^{137}Cs contents in cheese were calculated from these figures and from the $^{90}Sr/Ca$ and $^{137}Cs/K$ ratios in dried milk (cf. Tables 5.1.1 and 5.1.3). One kg of cheese appeared to contain 0.90 Bq ^{90}Sr and 0.080 Bq ^{137}Cs.

5.9.4. Grain products

Tables 5.9.1 and 5.9.2 show the estimates of ^{90}Sr and ^{137}Cs, respectively, in grain products consumed in 1980. From these tables, the activity levels in grain products were estimated at 0.38 Bq ^{90}Sr kg^{-1} and 0.24 Bq ^{137}Cs kg^{-1}.

5.9.5. Potatoes

The figures in Table 5.5.1 were used, i.e. 0.083 Bq ^{90}Sr kg^{-1} and 0.077 Bq ^{137}Cs kg^{-1}.

Table 5.9.1. Estimate of the ^{90}Sr content in grain products consumed per caput in 1980

Type	Fraction from harvest 1979			Fraction from harvest 1980			Total Bq
	kg flour	Bq kg^{-1}	Bq	kg flour	Bq kg^{-1}	Bq	
Rye flour 60% extraction	21.9	0.74	16.22	7.3	0.74	5.40	21.62
Wheat flour 75% extraction	32.9	0.15	4.87	10.9	0.17	1.81	6.68
Grits	5.5	0.30	1.63	1.8	0.31	0.55	2.18
Total	60.3	0.38	22.72	20.0	0.39	7.76	30.48

Table 5.9.2. Estimate of the ^{137}Cs content in grain products consumed per caput in 1980

Type	Fraction from harvest 1979			Fraction from harvest 1980			Total Bq
	kg flour	Bq kg^{-1}	Bq	kg flour	Bq kg^{-1}	Bq	
Rye flour 100% extraction	21.9	0.45	9.90	7.3	0.33	2.41	12.31
Wheat flour 75% extraction	32.9	0.14	4.75	10.9	0.12	1.25	6.00
Grits	5.5	0.16	0.88	1.8	0.13	0.23	1.11
Total	60.3	0.26	15.53	20.0	0.19	3.89	19.42

5.9.6. Vegetables

Table 5.6.3 shows the calculation of ^{90}Sr and ^{137}Cs in Danish vegetables consumed in 1980. The mean contents were 0.34 Bq ^{90}Sr kg^{-1} and 0.084 Bq ^{137}Cs kg^{-1}.

5.9.7. Fruit

The levels in imported fruit in 1980 are assumed to be equal to the mean levels found in oranges and bananas collected in Copenhagen in 1980, i.e. 0.06 Bq ^{90}Sr kg^{-1} and 0 Bq ^{137}Cs kg^{-1}. The mean levels in Danish fruit (apples) in 1980 were 0.044 Bq ^{90}Sr kg^{-1} and 0.044 Bq ^{137}Cs kg^{-1} (cf. 5.6). The daily mean consumption of fruit consisted of 100 g of Danish and 40 g of foreign origin. Hence the mean contents in fruit were 0.05 Bq ^{90}Sr kg^{-1} and 0.03 Bq ^{137}Cs kg^{-1}.

5.9.8. Meat

The annual mean values of ^{90}Sr and ^{137}Cs in meat were calculated from Table 5.8.1: 0.011 Bq ^{90}Sr kg^{-1} and 0.57 Bq ^{137}Cs kg^{-1}. (In a Danish diet meat comprises 2/3 pork and 1/3 beef).

5.9.9. Fish

The ^{90}Sr and ^{137}Cs contents in fish are estimated from 5.8.2 at 0.028 Bq ^{90}Sr kg^{-1} and 4.55 Bq ^{137}Cs kg^{-1}.

5.9.10. Eggs

The contents of activity in eggs were estimated from 5.8.3. The levels were 0.014 Bq ^{90}Sr kg^{-1} and 0.028 Bq ^{137}Cs kg^{-1}.

5.9.11. Coffee and tea

One third of the total consumption consists of tea and two thirds of coffee. The mean contents were in 1980 0.66 Bq ^{90}Sr kg^{-1} and 2.21 Bq ^{137}Cs kg^{-1} and these figures were used.

5.9.12. Drinking water

The ^{90}Sr level (population-weighted mean) found in drinking water collected in April 1979[1] was used as the mean level for drinking water, i.e. 0.0007 Bq ^{90}Sr kg^{-1}. The ^{137}Cs content in drinking water is assumed to be negligible.

Table 5.9.3. Estimate of the mean content of ^{90}Sr in the human diet in 1980

Type of food	Annual quantity in kg	Bq ^{90}Sr per kg	Total Bq ^{90}Sr	Percentage of total Bq ^{90}Sr in food
Milk and cream	164.0	0.127	20.83	23.6
Cheese	9.1	0.90	8.19	9.3
Grain products	80.3	0.38	30.48	34.6
Potatoes	73.0	0.083	6.06	6.9
Vegetables	43.8	0.34	14.89	16.9
Fruit	51.1	0.05	2.56	2.9
Meat	54.7	0.011	0.60	0.7
Eggs	10.9	0.014	0.15	0.2
Fish	10.9	0.028	0.31	0.4
Coffee and tea	5.5	0.66	3.63	4.1
Drinking water	548	0.0007	0.38	0.4
Total			88.08	

The mean Ca intake was estimated at 0.62 kg y^{-1} (approx. 0.2-0.25 kg creta praeparata). Hence the $^{90}Sr/Ca$ ratio in total diet was 142 Bq ^{90}Sr $(kg\ Ca)^{-1}$ (3.8 S.U.) in 1980.

5.9.13. Discussion

Tables 5.9.3 and 5.9.4 show the estimates of ^{90}Sr and ^{137}Cs in the Danish diet in 1980. The figures should be compared with the levels calculated from the total-diet samples (cf. 5.7). The ^{90}Sr estimates obtained by the two methods (cf. also fig. 5.7.1) were 142 Bq (kg Ca)$^{-1}$ and 157 Bq (kg Ca)$^{-1}$, respectively, and the ^{137}Cs estimates were 0.39 Bq ^{137}Cs (day)$^{-1}$ and 0.37 Bq ^{137}Cs (day)$^{-1}$.

The ratio between observed and predicted (cf. Appendix C) diet levels was 0.97 for ^{90}Sr and 1.01 for ^{137}Cs (corrected for Windscale ^{137}Cs).

Table 5.9.4. Estimate of the mean content of ^{137}Cs in the human diet in 1980

Type of food	Annual quantity in kg	Bq ^{137}Cs per kg	Total Bq ^{137}Cs	Percentage of total Bq ^{137}Cs in food
Milk and cream	164.0	0.111	18.20	12.8 (18.6)
Cheese	9.1	0.080	0.73	0.5 (0.7)
Grain products	80.3	0.24	19.42	13.6 (19.9)
Potatoes	73.0	0.077	5.62	4.0 (5.7)
Vegetables	43.8	0.084	3.68	2.6 (3.8)
Fruit	51.1	0.03	1.53	1.1 (1.6)
Meat	54.7	0.57	31.18	21.9 (31.9)
Eggs	10.9	0.028	0.31	0.2 (0.3)
Fish	10.9	4.55	49.60(4.96)	34.8 (5.1)
Coffee and tea	5.5	2.21	12.16	8.5 (12.4)
Drinking water	548	0	0	0 (0)
Total			142.43 (97.79)	

In brackets are shown the values if the contribution of Windscale ^{137}Cs in fish is excluded. This contribution is approx. 90% of the ^{137}Cs content in Danish fish. Windscale thus contributed with approximately 30% of the total ^{137}Cs content in Danish diet in 1980.

As the approximate intake of potassium was 1.365 kg y^{-1} the ^{137}Cs/K ratios were 104 (71.6) Bq ^{137}Cs (kg K)$^{-1}$ or 2.8 (1.93) M.U. in 1980.

The relative contributions of ^{90}Sr from milk products (~ 33%) and from grain (35%) were similar to those in 1978 and 1979. The contribution from potatoes, other vegetables, and fruit was ~ 27%, i.e. a little higher than in 1979. The relative contribution of ^{137}Cs in the total diet changed from 1979 to 1980 as follows: milk products (16 to 13%), grain products decreased from 28 to 14%, and meat increased (19 to 22%). Fish contributed 35% to the total ^{137}Cs intake in 1980, and is thus the most important source of ^{137}Cs. This is, however, due to the ^{137}Cs contribution from Windscale. If this was excluded, milk products would contribute with 19%, grain: 20%, meat: 32% and fish: 5%.

5.10. Grass collected around Risø

Table 5.10.1 shows the ^{90}Sr content in grass ash from Zealand in 1980. The mean ^{90}Sr activity was 51 Bq ^{90}Sr (kg ash)$^{-1}$, or 1080 Bq ^{90}Sr (kg Ca)$^{-1}$, i.e. the 1980 level was aprroximately equal to the 1979 level. Figure 5.10 shows the ^{90}Sr concentration in grass since 1957. The ratio between observed and predicted (cf. Appendix C.1) ^{90}Sr level in grass in 1980 was 1.88.

Table 5.10.1. Strontium-90 in grass from Zealand, 1980

	Bq ^{90}Sr (kg ash)$^{-1}$	Bq ^{90}Sr (kg Ca)$^{-1}$
Jan-March	39	1110
April-June	64	1210
July-Sept	55	1090
Oct-Dec	46	890
Mean	51	1080
Mean	1.38 pCi g^{-1}	29 S.U.

Table 5.10.2 shows the ^{137}Cs content in grass collected weekly in the spring at Risø. The ^{137}Cs levels decrease from March to May due to growth dilution. The decrease is most pronounced for the ^{137}Cs/K ratios, which decreased by a factor of four.

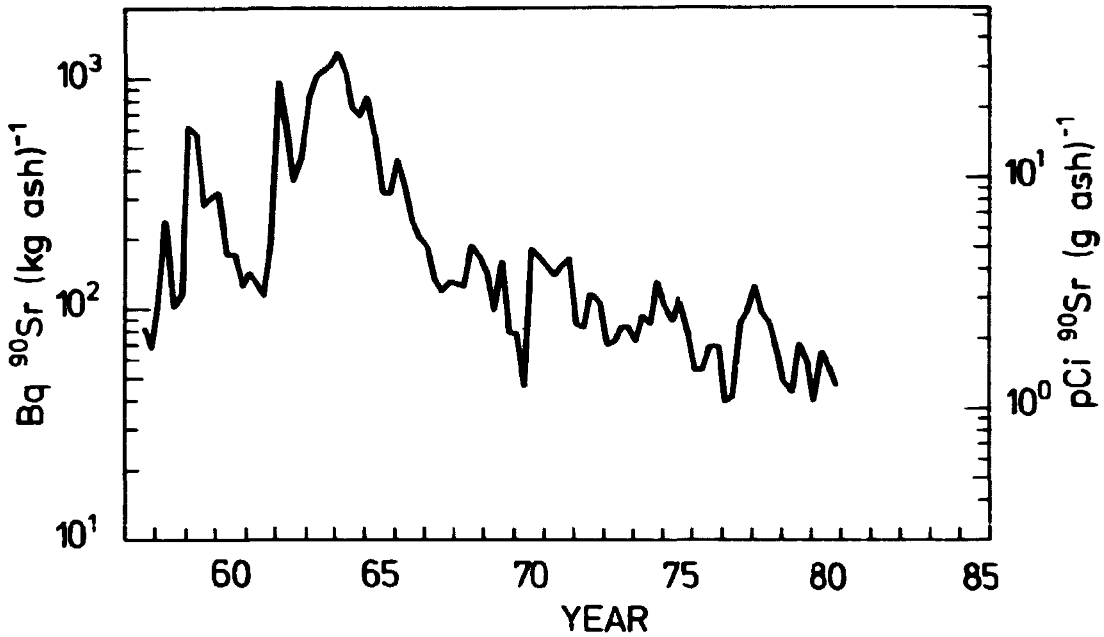


Fig. 5.10. Quarterly ^{90}Sr levels in grass, 1957-1980.

Table 5.10.2. Cesium-137 in grass from Risø, 1980

	n	Bq ^{137}Cs kg^{-1} fresh	Bq ^{137}Cs m^{-2}	Bq ^{137}Cs (kg K)$^{-1}$
March	5	3.51±0.13	1.23±0.16	1010± 70
April	4	3.39±0.86	1.38±0.26	880±220
May	3	1.69±0.60	0.84±0.25	250± 90

The error term is 1 S.E. of the mean of n samplings during the month.

5.11. Sea plants

5.11.1. Sea plants collected in Roskilde Fjord

Figure 5.11.1 shows the Bq ^{90}Sr (kg Ca)$^{-1}$ levels in sea plants since 1959 and Table 5.11.1 the results for 1980. The mean level in Fucus vesiculosus was 390 Bq ^{90}Sr (kg Ca)$^{-1}$, and in Zostera marina 70 Bq ^{90}Sr (kg Ca)$^{-1}$. The mean ratio between observed and predicted ^{90}Sr levels in sea plants was 0.81.

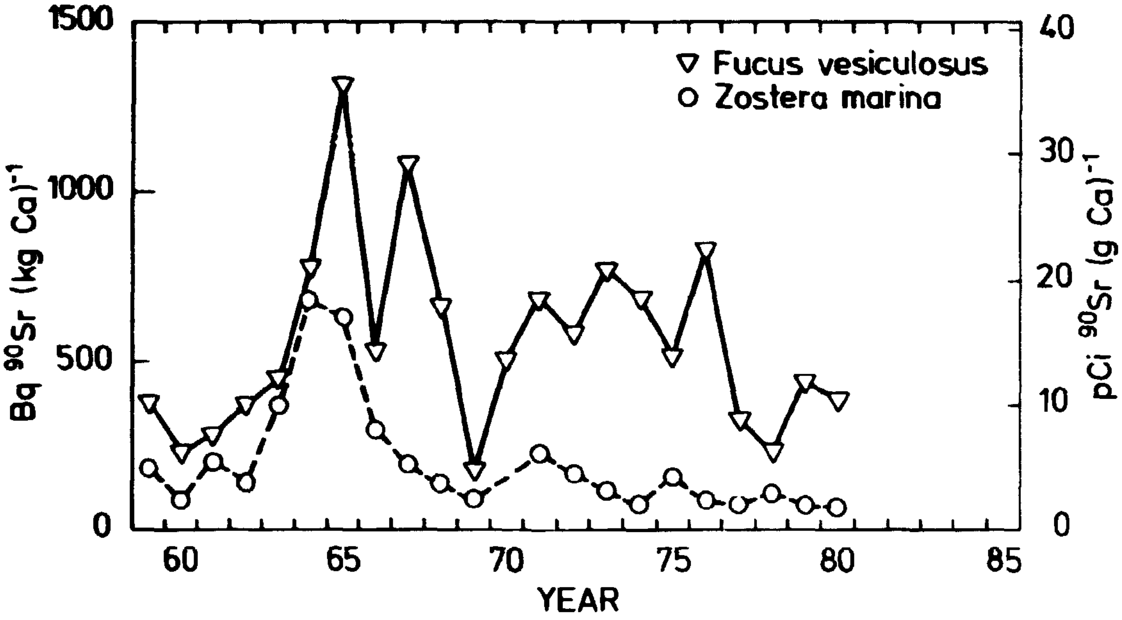


Fig. 5.11.1. Strontium-90 in sea plants from Roskilde fjord, 1959-1980.

Table 5.11.1. Strontium-90 and Cesium-137 in sea plants from Roskilde Fjord in 1980

Location	Species	Date	Bq ^{90}Sr (kg Ca)$^{-1}$	Bq ^{90}Sr kg^{-1} fresh weight	Bq ^{137}Cs (kg K)$^{-1}$	Bq ^{137}Cs kg^{-1} fresh weight
III	Zostera marina	July 25	64	0.22	52	0.23
IX	- " -	- " -	75	0.22	34	0.11
I	Fucus vesiculosus	Aug 6	280	1.09	300	2.20
I	- " -	Oct 22	380	1.42	290	1.92
I	- " -	Dec 12	520	1.84	250	1.85

Zostera marina contained 43 Bq ^{137}Cs (kg K)$^{-1}$ and Fucus vesiculosus 280.

5.11.2 Brown algae collected in Danish waters in 1980

In Table 3.2.1.4 measurements on fucoids collected in the Sound are presented, and Table 5.11.1 shows the data from Roskilde Fjord. Besides these samples, brown algae have been collected in the Baltic Sea at Bornholm and Rødvig, in the Kattegat at Anholt, Endelave and Skagen, and in the Great Belt at Halskov Rev (cf. Table 5.11.2).

Table 5.11.2. Gamma-emitting radio nuclides in brown algae collected in inner Danish waters (except the Sound) in 1980

Location	Species	Date	Bq ^{137}Cs kg^{-1} fresh weight	Bq ^{137}Cs (kg K)$^{-1}$	Bq ^{60}Co kg^{-1} fresh weight
Anholt harbour	Fucus ves.	May 4	1.98 (12.9)	450	0.07
Endelave	- " -	April 22	2.11 (13.3)	520	-
Bornholm Svenskehavn	- " -	June 3	1.42 (8.3)	340	-
Bornholm Arnager	- " -	June 3	1.43 (12.3)	410	-
Bornholm Hammeren	- " -	June 3	1.03 (8.5)	250	-
Anholt harbour	- " -	Oct 11	2.19 (10.5)	430	0.3
Rødvig Korsnæb	- " -	Aug 6	1.86 (9.7)	380	-
Halskov Rev	- " -	Aug 2	2.38*(10.7)	400	-
Bornholm Listed	- " -	Aug 19	2.39 (12.9)	380	-
Skagen	Laminaria	July 22	2.16 (10.9)	270	-

In brackets are shown Bq ^{137}Cs kg^{-1} dry weight.

*^{134}Cs/^{137}Cs = 0.045

Table 5.11.3 indicates that there was no difference between the ^{137}Cs concentrations in brown algae from the various Danish waters. As the ^{137}Cs concentration is nearly proportional to the salinity (cf. 4.4) we conclude that ^{137}Cs is concentrated more in low- than in high-salinity waters. A similar conclusion was drawn in 1979 (cf. Risø-R-421 p. 112[1])). The ratio between Bq kg^{-1} dry weight sea plant and Bq l^{-1} sea water was approximately 170 in the Kattegat, 360 in the Sound and Roskilde Fjord, and 690 in the Baltic Sea.

Furthermore, it is evident that the variance of the dry weight data, in general, are less than that of the fresh weight figures. As compared to 1979 the ^{137}Cs concentrations in Danish fucoids increased with 10-15% in 1980. According to fig. 4.4.6 the ^{137}Cs concentrations in "typical Danish surface water" (16 o/oo salinity) increased from 1979 to 1980 by 14% (cf. also 8.2.3).

Table 5.11.3. Resume of ^{137}Cs measurements on fucoids and laminaria collected in Danish waters in 1980

Water	Number of samples	Bq ^{137}Cs kg^{-1} fresh weight	Bq ^{137}Cs kg^{-1} dry weight	Approximate salinity range where the samples are collected
The Kattegat	4	2.1±0.05	11.9±0.7	20-30 o/oo
The Sound	10	2.5±0.2	11.7±0.5	10-15 o/oo
Roskilde Fjord	3	2.0±0.1	9.9±0.8	10-15 o/oo
The Great Belt	1	2.4	10.7	15-20 o/oo
The Baltic Sea	5	1.6±0.2	10.3±1.0	5-10 o/oo
Total mean	23	2.16±0.13	11.16±0.35	
Mean		58 pCi kg^{-1} f.w.	300 pCi kg^{-1} d.w.	

The error term is 1 S.E. of the mean.

6. STRONTIUM-90 AND CESIUM-137 IN MAN IN 1980

by A. Aarkrog and J. Lippert

6.1. Stronium-90 in human bone

The collection of human vertebrae from the institutes of forensic medicine in Copenhagen and Århus was continued in 1980. As in the total-diet survey (cf. 5.7), the country was divided into eight zones. The samples were divided into five age groups: new-born (< 1 month), infants (1 month-4 years), children and teenagers (5-19 years), adults ($\leq$ 29 years), and adults (> 29 years), however, no samples of new-borns bone were obtained in 1980.

Tables 6.1.2-6.1.5 show the results for the four groups. The ^{90}Sr concentrations in human bone collected in 1980 were unchanged from those observed in 1979.

Table 6.1.1. Strontium-90 in bone from new-born children (< 1 month old) in 1980

No samples.

Table 6.1.2. Strontium-90 in bone from infants ($\leq$ 4 years) in 1980

Zone	Age in years and months	Month of death	Sex	Bq (kg Ca)$^{-1}$
II	2 m	3	M	46
VI	2 m	2	M	40 A
"	1 y 1 m	2	F	7 B
"	1 y 5 m	2	F	34

Table 6.1.3. Strontium-90 in bone from children and teenagers (≤ 19 years) in 1980

Zone	Age in years	Month of death	Sex	Bq (kg Ca)$^{-1}$
II	14	10	M	36
III	19	3	F	36
VI	16	2	F	21
"	16	9	M	21
"	19	9	M	24

Table 6.1.4. Strontium-90 in vertebrae from adults (≤ 29 years) in 1980

Zone	Age in years	Month of death	Sex	Bq (kg Ca)$^{-1}$
II	21	10	M	26
"	24	10	M	32
VI	29	2	F	27

Table 6.1.5. Strontium-90 in vertebrae from adults (> 29 years) in 1980

Zone	Age in years	Month of death	Sex	Bq (kg Ca)$^{-1}$
II	39	10	F	33
"	70	2	F	31
"	72	2	F	35
"	74	10	F	29
"	30	3	M	23
"	40	2	M	29
"	49	3	M	30
"	56	3	M	28
"	59	2	M	59
"	81	10	M	40
"	83	10	M	38
III	58	3	F	26
"	47	6	M	28
IV	37	3	M	22
"	39	10	M	31
"	60	10	M	30
"	75	10	M	44
VI	39	2	F	24
"	31	2	M	40
"	37	2	M	47

Table 6.1.6. Strontium-90 in human vertebrae collected in Denmark in 1980. (Unit: Bq (kg Ca)$^{-1}$)

Age group	Number of samples	Min.	Max.	Median	Mean
Infants (≤ 4 years)	4	7	46	37	32
Children (≤ 19 years)	5	21	36	24	28
Adults (≤ 29 years)	3	26	32	27	28
Adults (> 29 years)	20	22	59	30	33

The observed mean concentration in adults (≥ 30 years) was 76% of that predicted (cf. Appendix C).

Tables 6.1.7-6.1.10 show ANOVA's on the adult ($\geq$ 30 years) bone data from E. Jutland (zone II) and Zealand (zone VI). The data were divided into two periods: one with "high" levels (1964-1968) and "low" error, and another (1960-1963 and 1969-1980) with "low" levels and "high" error. The purpose of this division was to see if we could detect any significant difference in ^{90}Sr levels between male and female vertebrae. It appears that this was not possible in the present material.

Table 6.1.7. Analysis of variance of ln Bq ^{90}Sr (kg Ca)$^{-1}$ in vertebrae from adults ($\geq$ 30 years) collected in E-Jutland (Zone II), 1964-1968. (Age groups: 30-39, 40-49, 50-59, 60-69, 70-79 and 80-89 years)

Variation	SSD	f	s^2	v^2	P
Between year (Y)	0.099	4	0.025	0.298	-
" sex (S)	0.176	1	0.176	2.120	-
" age group (A)	0.930	5	0.186	2.241	-
" Y × S	0.181	3	0.060	0.726	-
" S × A	0.638	5	0.128	1.532	-
" Y × A	0.428	11	0.039	0.468	-
" Y × S × A	0.736	5	0.147	1.774	-
Remainder	1.665	20	0.083		

Table 6.1.8. Analysis of variance of ln Bq ^{90}Sr (kg Ca)$^{-1}$ in vertebrae from adults ($\geq$ 30 years) collected in Zealand (Zone VI), 1964-1968. (Age groups: 30-39, 40-49, 50-59, 60-69, 70-79 and 80-89 years)

Variation	SSD	f	s^2	v^2	P
Between year (Y)	0.079	3	0.026	0.376	-
" sex (S)	0.148	1	0.148	2.114	-
" age group (A)	0.723	5	0.145	2.066	-
" Y × S	0.120	1	0.120	1.714	-
" S × A	0.076	3	0.025	0.362	-
" Y × A	0.466	6	0.078	1.109	-
Remainder	1.045	15	0.070		

Table 6.1.9. Analysis of variance of ln Bq ^{90}Sr (kg Ca)$^{-1}$ in vertebrae from adults (≥ 30 years) collected in Jutland (Zone II), 1960-1963 and 1969-1980. (Age groups: 30-39, 40-49, 50-59, 60-69, 70-79 and 80-89 years)

Variation		SSD	f	s^2	v^2	P
Between	year (Y)	13.973	13	1.075	10.538	> 99.95%
"	sex (S)	0.152	1	0.152	1.490	-
"	age group (A)	0.819	5	0.164	1.606	-
"	Y × S	1.730	12	0.144	1.417	-
"	S × A	0.488	5	0.098	0.960	-
"	Y × A	3.019	38	0.079	0.781	-
"	Y × S × A	2.275	22	0.103	1.016	-
Remainder		9.567	94	0.102		

Table 6.1.10. Analysis of variance of ln Bq ^{90}Sr (kg Ca)$^{-1}$ in vertebrae from adults (≥ 30 years) collected in Zealand (Zone VI), 1960-1963 and 1969-1980. (Age groups: 30-39, 40-49, 50-59, 60-69, 70-79 and 80-89 years)

Variation		SSD	f	s^2	v^2	P
Between	year (Y)	9.726	14	0.695	5.938	> 99.95%
"	sex (S)	0.009	1	0.009	0.077	-
"	age group (A)	0.909	4	0.227	1.942	-
"	Y × S	1.794	11	0.163	1.397	-
"	S × A	0.194	2	0.097	0.830	-
"	Y × A	2.295	19	0.121	1.035	-
"	Y × S × A	0.262	3	0.087	0.747	-
Remainder		8.873	76	0.117		

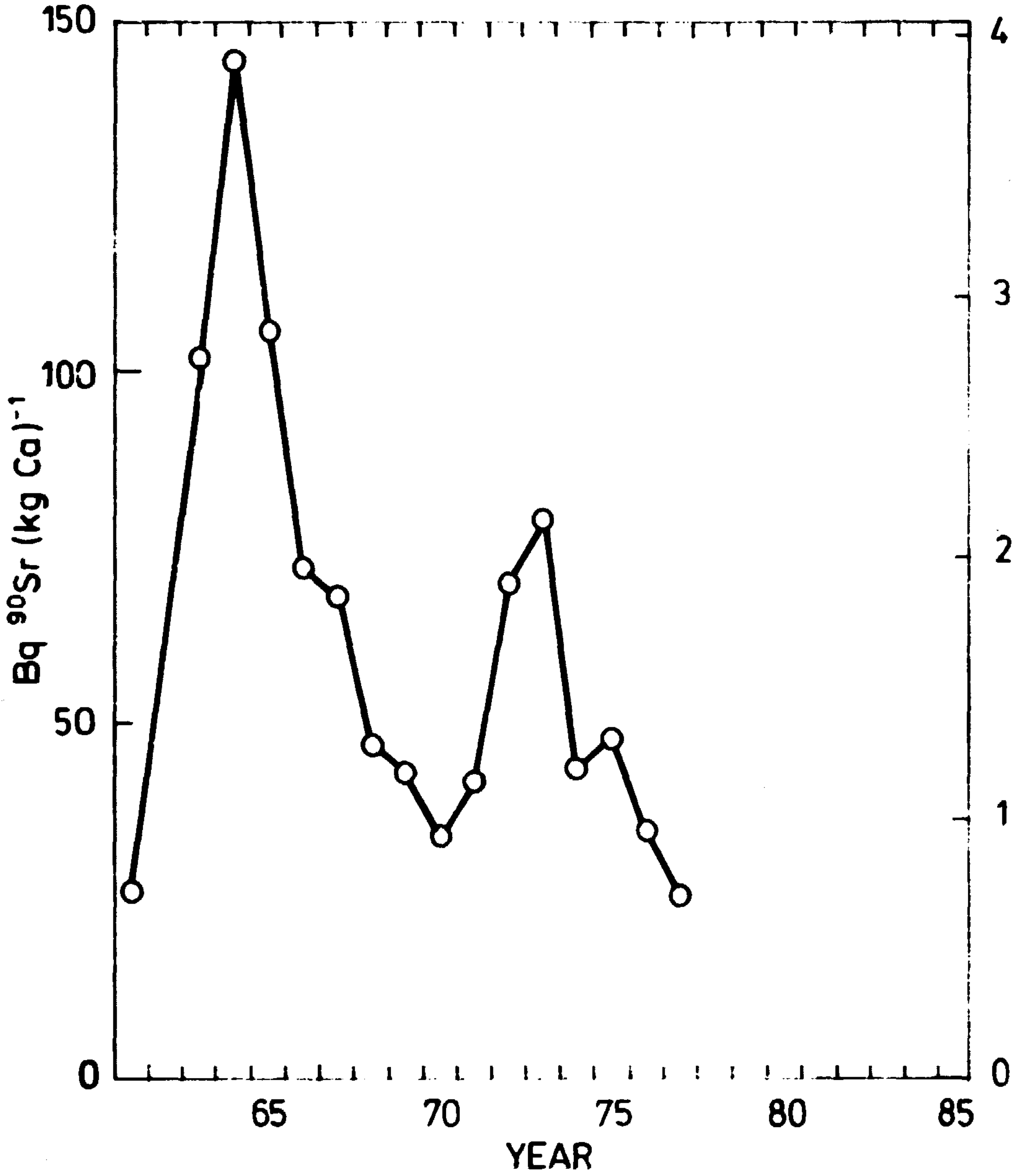


Fig. 6.1.1. Strontium-90 levels (sample number weighted mean) in bone from newborn (< 1 month) 1961-1980.

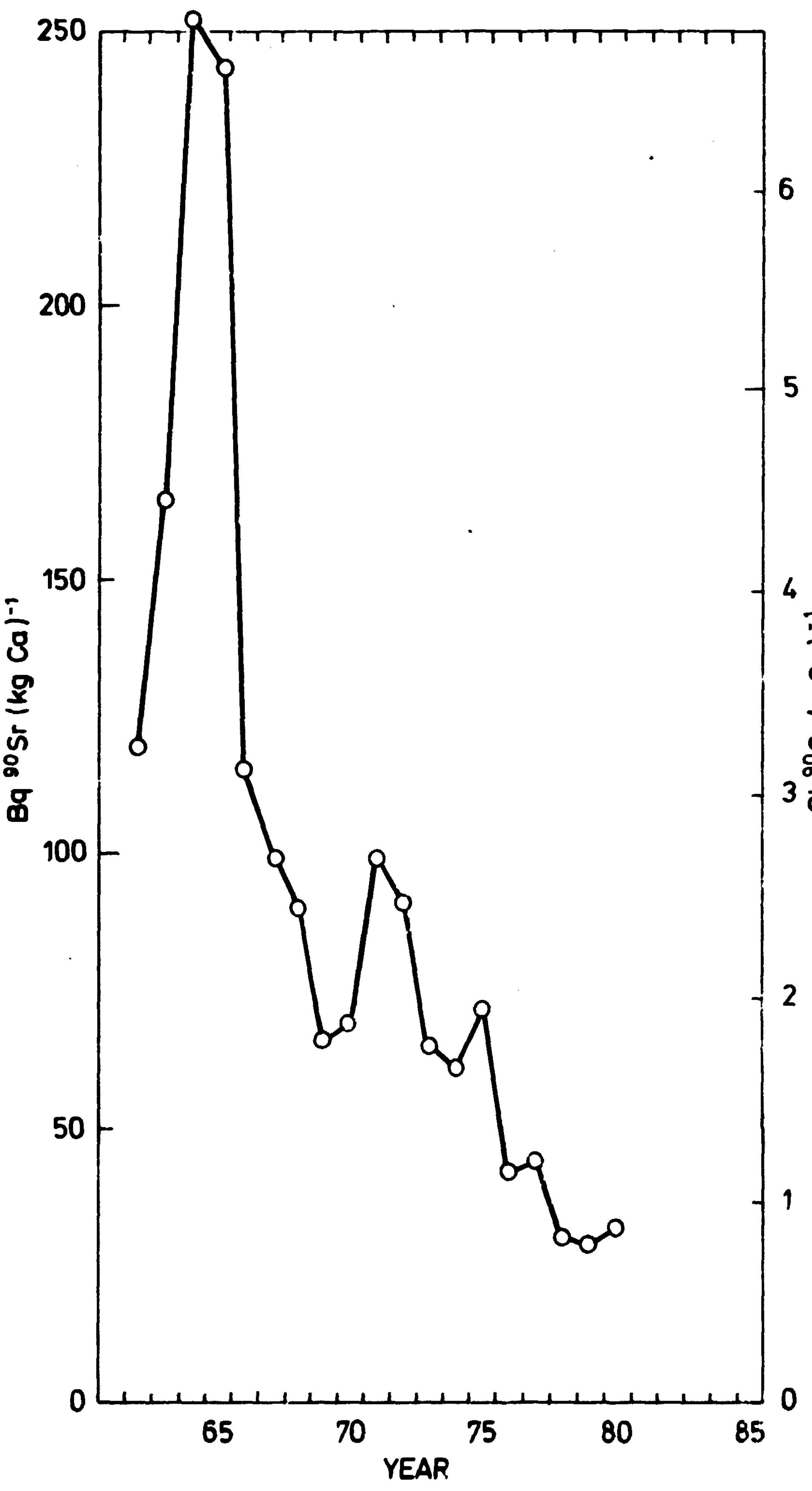


Fig. 6.1.2. Strontium-90 levels (sample number weighted mean) in bone from infants (> 1 month ≤ 4 years) 1962-1980.

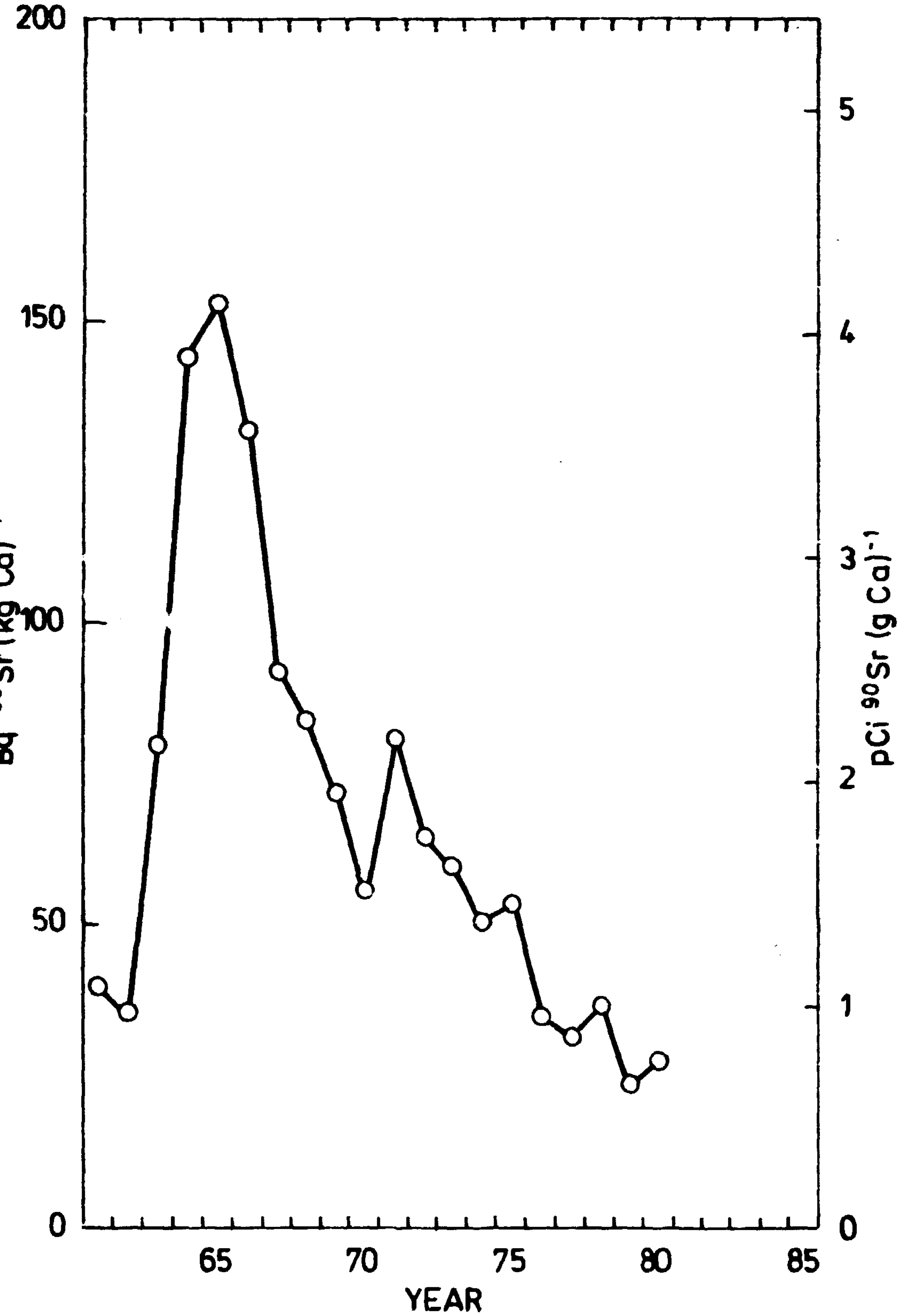


Fig. 6.1.3. Strontium-90 levels (sample number weighted mean) in bone from children (> 4 years $\leq$ 19 years) 1961-1980.

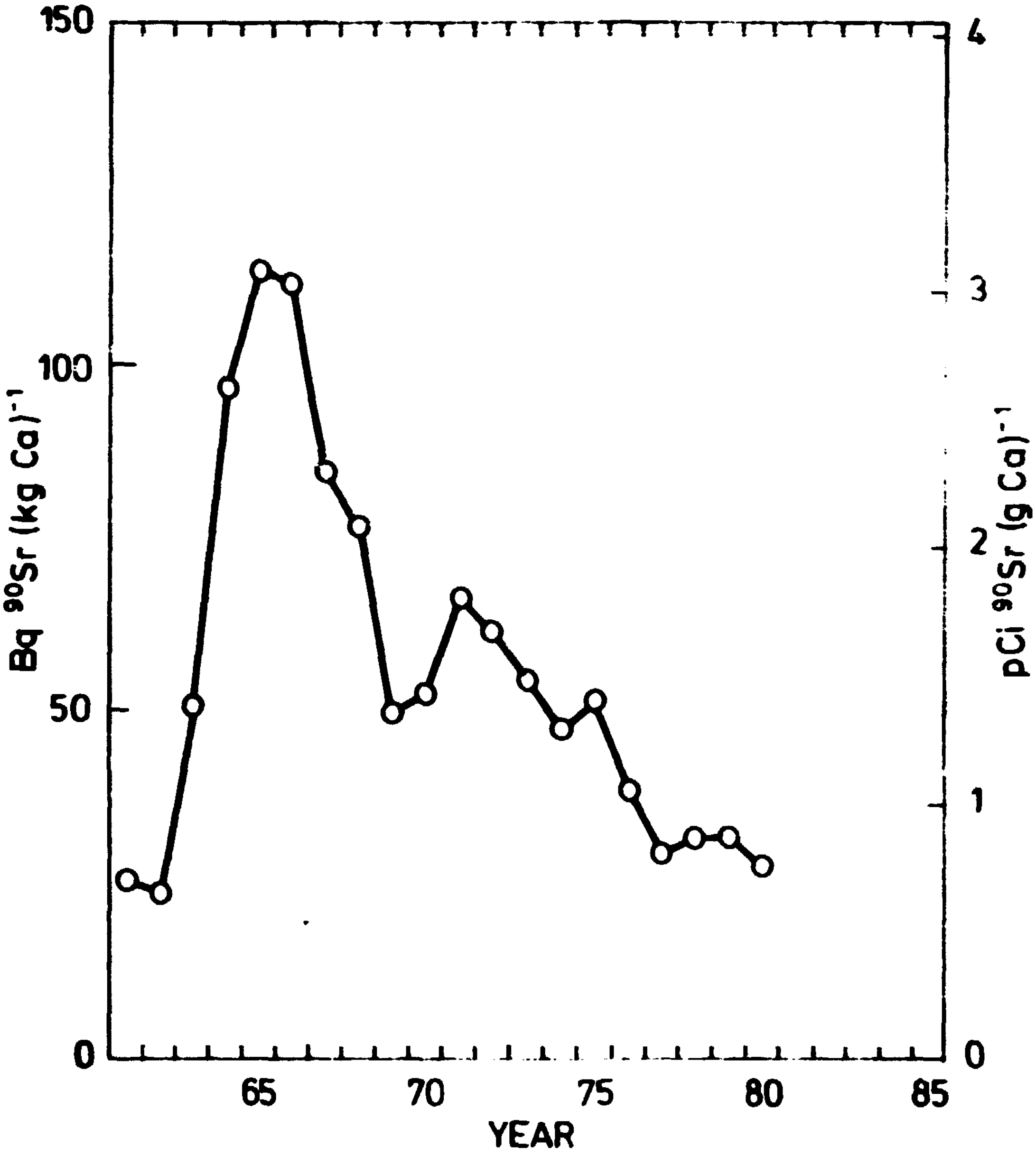


Fig. 6.1.4. Strontium-90 levels (sample number weighted mean) in bone from adults (> 19 years ≤ 29 years) 1961-1980.

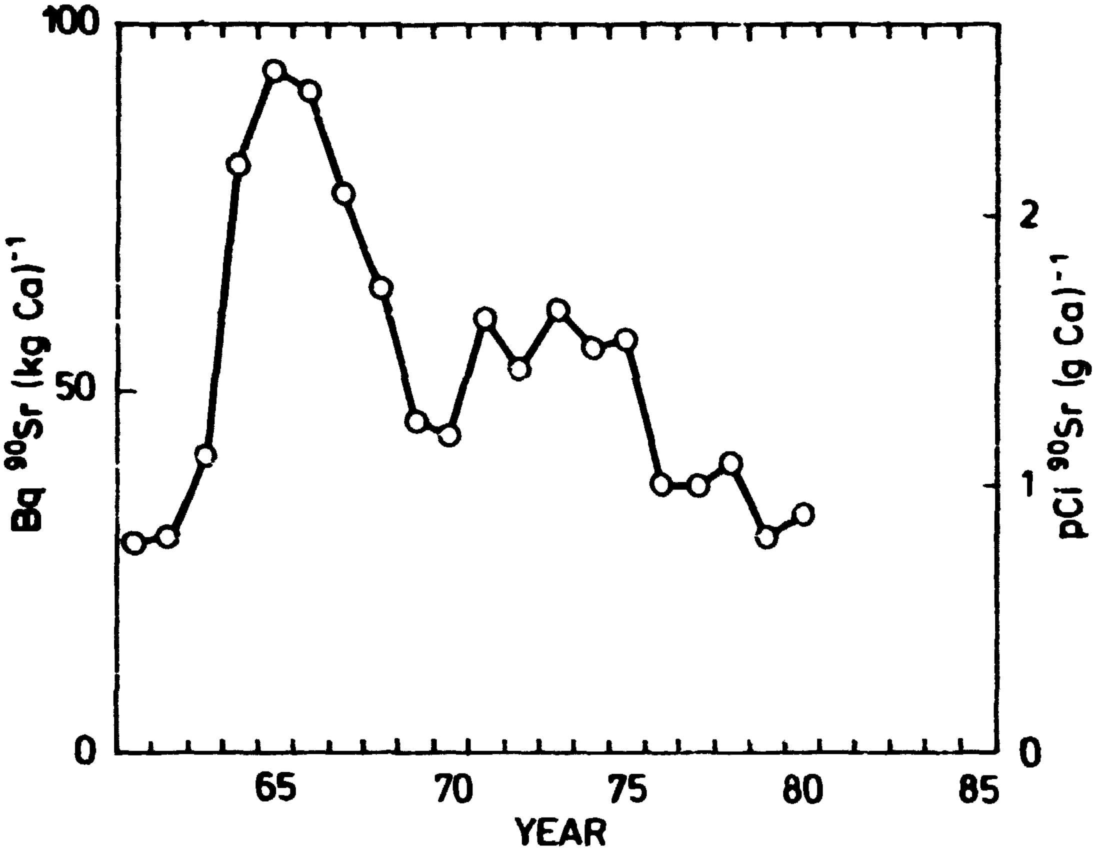


Fig. 6.1.5. Strontium-90 levels (sample number weighted mean) in bone from adults (> 29 years) 1961-1980.

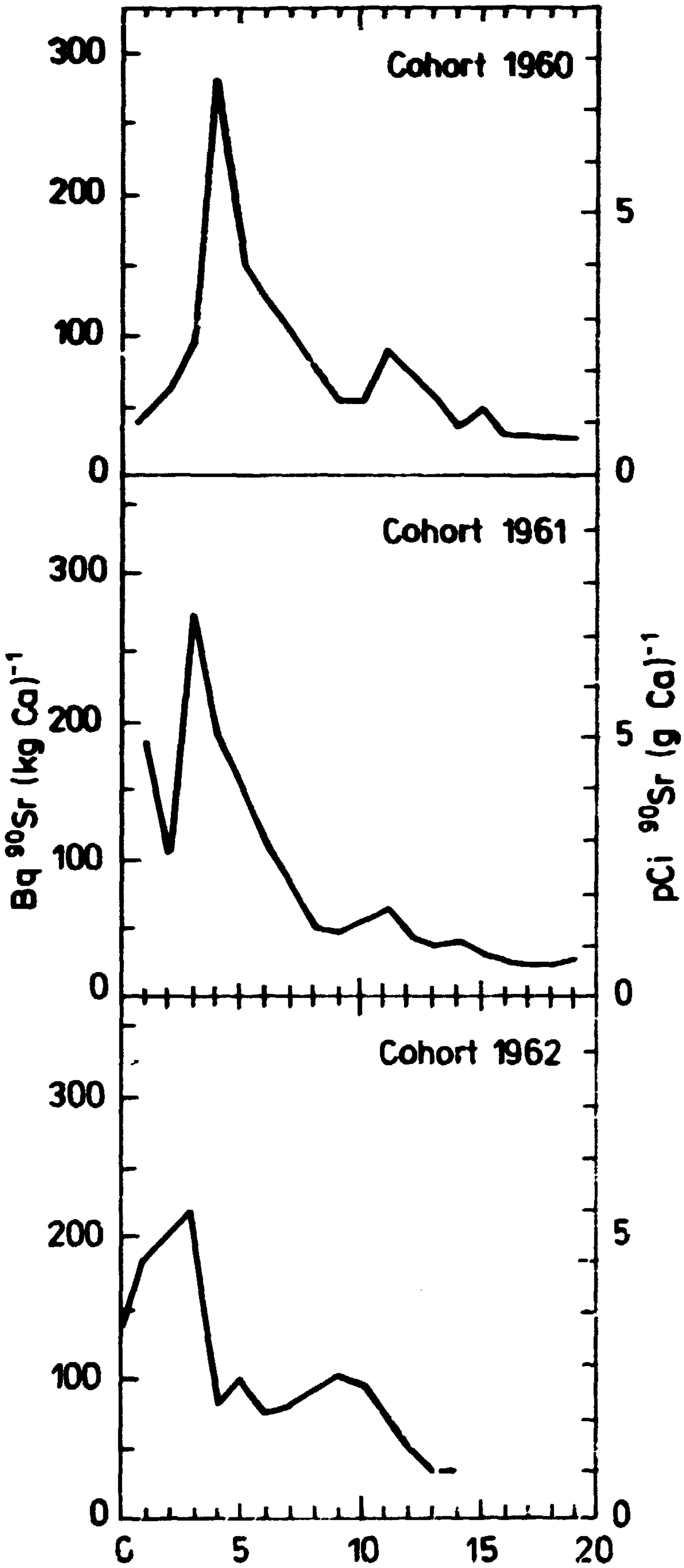
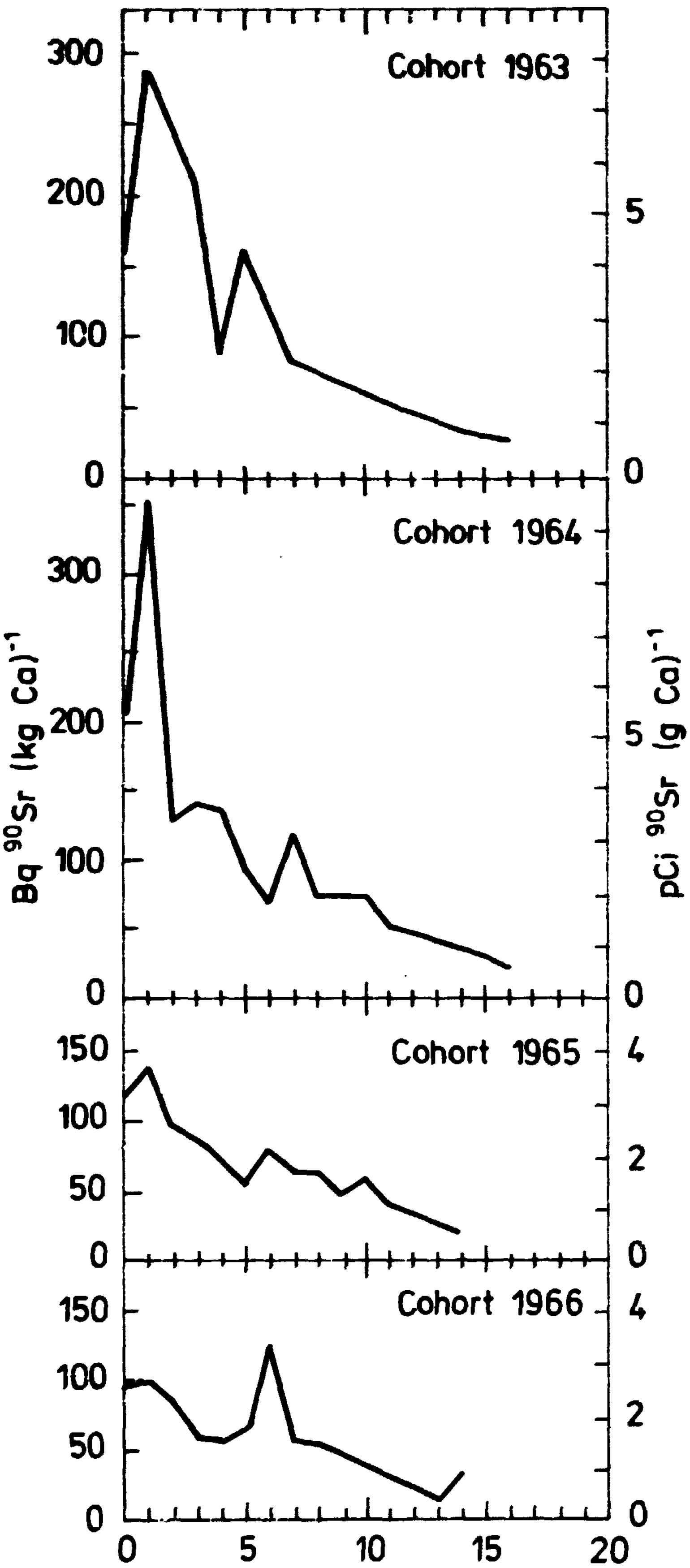


Fig. 6.1.6. Strontium-90 in human bone from Danish cohorts 1960–1966. Abscissa: age in years. Ordinate: bone level in Bq ^{90}Sr (kg Ca)$^{-1}$.


Cohort 1963
Cohort 1964
Cohort 1965
Cohort 1966
Bq ^{90}Sr (kg Ca)$^{-1}$
pCi ^{90}Sr (g Ca)$^{-1}$
300
200
100
0
150
50
5
4
2
0
5
10
15
20

6.2. Cesium-137 in the human body

Whole-body measurements were initiated at Risø in July 1963 (cf. 2.3 in Risø Report No. 85[1]). A control group from the Health Physics Department was selected and has since then been measured as far as possible three times a year.

However, due to the decreasing ^{137}Cs content in the body the contribution from interfering radionuclides to the γ-spectra has made the determination of ^{137}Cs unreliable and since 1978 we have not published whole-body measurements. From the prediction model

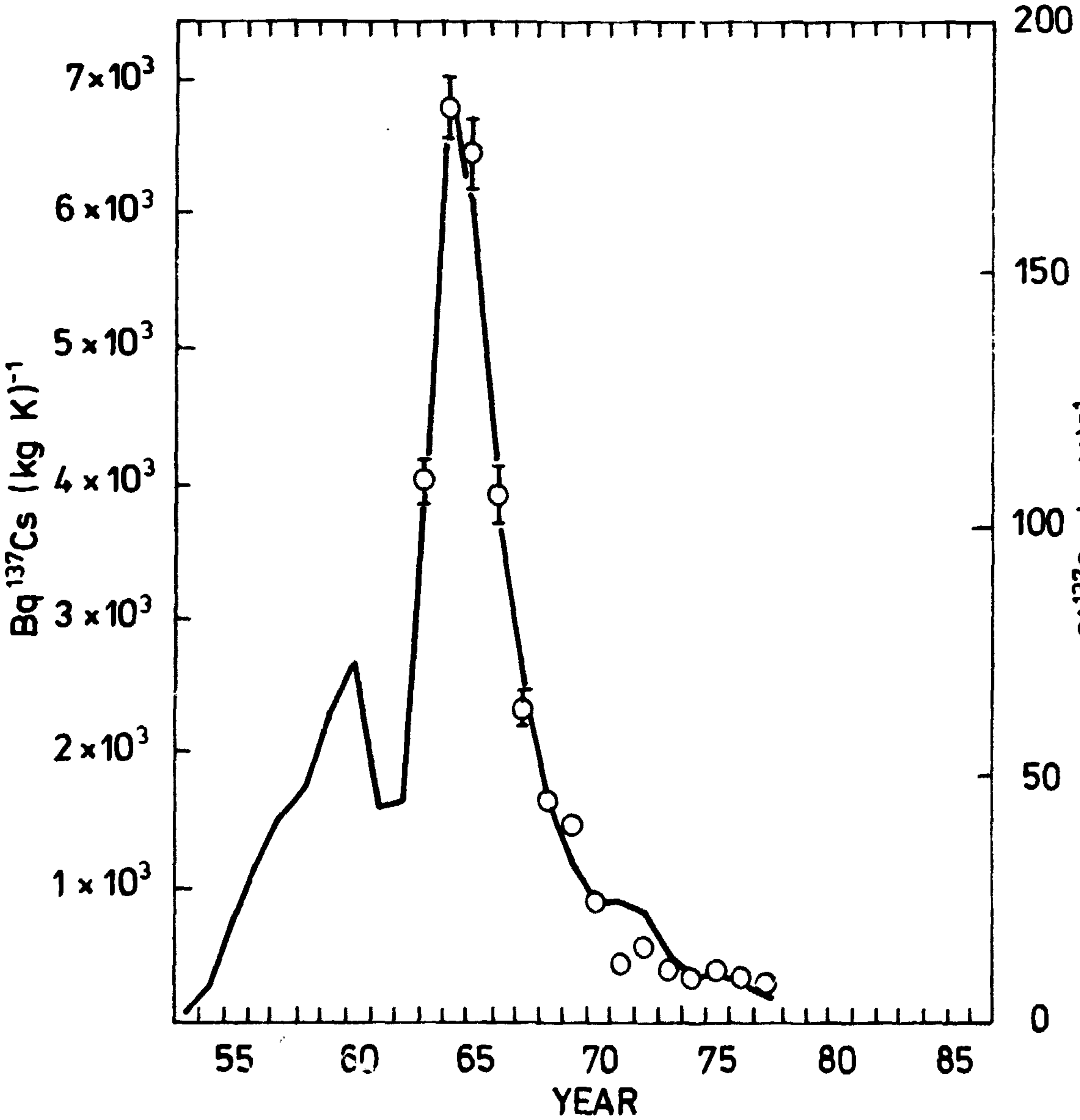


Fig. 6.2. A comparison between observed (±1 S.E.) and calculated[21] Bq ^{137}Cs $(kg\ K)^{-1}$ levels in whole-body from the Islands.

for whole body ^{137}Cs[21] we have estimated the level in 1980 at 162 Bq ^{137}Cs (kg K)$^{-1}$ (= 4.4 M.U.) and from the diet measurements (cf. 5.7) for the Islands our estimate becomes: 2.85·77 = 219 Bq ^{137}Cs (kg K)$^{-1}$ (= 5.9 M.U.), where 2.85 is the observed ratio between $^{137}Cs/K$ in body and diet[21].

7. TRITIUM IN THE ENVIRONMENT

by Heinz Hansen

7.1. Introduction

Tritium is produced naturally in the atmosphere by the interaction of cosmic-ray protons and neutrons with nitrogen, oxygen or argon. Surface waters contain about 0.37 kBq m^{-3} from this source[25]. Tritium is also produced and injected into the stratosphere as the result of thermonuclear explosions. At present, this latter source has enhanced the natural inventory by about a factor of ten[25]. Finally, tritium is produced as a by-product of the peaceful uses of atomic energy: it is released both during reactor operation and fuel reprocessing.

Before Denmark builds any nuclear power stations of her own, it is of interest to know the general tritium levels in the environment that could be affected by this new energy source. Also, an assay of the current tritium levels can be used already now to control any tritium which may be released from the Swedish nuclear power stations at Barsebäck and Ringhals, and from the reprocessing plants at Windscale and La Hague.

7.2. Assay of tritium in low-level amounts

The present assays of tritium levels in water are based on a relative enrichment of ^3H_2O by electrolysis and subsequent liquid scintillation counting as previously described (Risø Reports Nos. 386, 403)[1].

In spite of a series of adaptions of the original method, based on further experience, we have not yet quite resolved the problem that a few sea water samples show apparently enhanced tritium levels, which decay with storage time.

7.3. Results

Local precipitation values at Risø were affected by changes in the cooling system of the reactor DR 3, which in autumn 1980 resulted in a minor extra release of ^3H_2O to the environment.

Table 7.3.1. Tritium in precipitation collected at Risø in 1980

Month	Small (1 m^2) rain collector			Large (10 m^2) rain collector		
	m	kBq m^{-3}	kBq m^{-2}	m	kBq m^{-3}	kBq m^{-2}
Jan	0.020	6.7±0.19	0.133	0.024	-	-
Feb	0.019	6.7±0.19	0.126	0.020	-	-
March	0.015	4.4±0.74	0.067	0.015	-	-
April	0.025	9.6±0.93	0.24	0.028	11.1±0.37	0.31
May	0.020	11.1±0.56	0.22	0.010	8.9±0.93	0.089
June	0.077	7.4±0.19	0.57	0.076	12.6±0.56	0.96
July	0.084	7.0±0.74	0.59	0.083	11.5±0.37	0.96
Aug	0.060	9.8±2.0	0.59	0.041	-	-
Sept	0.062	-	-	0.072	-	-
1-27/10	0.072	48 ±6.1	3.5	0.048	32 ±3.1	1.54
27-30/10				0.028	113 ±2.0	3.2
Nov	0.060	7.0±0.37	0.42	0.061	-	-
Dec	0.051	4.3±0.56	0.22	0.038	5.6±0.74	0.21
	Σ_m 0.565			Σ_m 0.544		

The error term is 1 S.E. of the mean of double determinations.

Table 7.3.2. Tritium in ground water collected in March 1980 (cf. 4.3.1)

Location	kBq ^3H m^{-3}
Hvidsten	2.0 ±1.30
Feldbæk	2.2
Rømø	0.56±0.18
Rønne new	0.74±0.00
Rønne old	3.7
Hasselø	4.4 ±0.00
Fåretofte	9.6 ±0.37
Kalundborg	8.9 ±1.11
Ravnholt	11.8 ±1.11
Fredericia	5.7 ±0.92
Mean	5.0 ±3.9 (1 S.D.)
Mean: nCi l^{-1}	0.134±0.105 (1 S.D.)
Median	4.0
Median: nCi l^{-1}	0.109

A sample of ground water from Maglekilde in Roskilde contained 9.6±1.11 kBq ^3H m^{-3}.

The error term is 1 S.E. of the mean of double determinations.

Table 7.3.3. Tritium in sea water collected in Roskilde fjord (I) (cf. Fig. 4.6.2), 1980

Date	kBq ^3H m^{-3}
30/1	7.4±0.00
4/3	6.7±0.92*
8/4	7.8±1.48
6/5	6.7±0.74
3/6	11.1±0.44*
3/9	9.8±0.18
3/11	20.8±1.52*

The error term is 1 S.E. of the mean of double determinations.
*Triple determinations.

A regression analysis of the overall relation between sea water salinity (o/oo) and tritium content (nCi l^{-1}) in late 1979 (Table 7.3.4) and 1980 (Table 7.3.5) showed no significant changes from the figures for early 1979 quoted in our last report (Risø-R-421[1]). In early 1979 we had found: nCi ^3H l^{-1} = 0.28-0.0064 o/oo. Now we find for late 1979: nCi ^3H l^{-1} = 0.31-0.0073 o/oo, and for all 1979: nCi ^3H l^{-1} = 0.28-0.0066 o/oo. For 1980 we find: nCi ^3H l^{-1} = 0.34-0.0071 o/oo. This shows again that the tritium contamination of Danish waters is predominantly due to fallout ^3H_2O in precipitation. It is not affected to any significant extent by tritium from Windscale or from Swedish nuclear plants.

Table 7.3.4. Tritium in sea water collected in 1979 and January 1980 (cf. Risø-R-421[1])

Location	Position or station number N	E	Depth in m	Date	kBq m^{-3} ±1 S.E.	Salinity o/oo
Kullen	56°15'	12°25'	0	Nov 1979	5.7 ±1.66	25.7
- " -	- " -	- " -	22	- " -	4.4 ±0.37	26.3
Hesselø			0	Jan 1980	5.4 ±0.18	22.9
Kattegat SW			0	- " -	5.9 ±0.37	20.0
Asnæs rev			0	- " -	5.7 ±0.85*	18.7
Halskov rev			0	- " -	5.6 ±0.85*	15.5
Femern bælt			0	- " -	6.8 ±0.56	17.4
Gedser rev			0	- " -	10.7 ±0.37	11.7
The Sound - North A	55°48'	12°44'	0	Dec 1979	5.0 ±0.18	26.2
- " - - " -	- " -	- " -	19	- " -	3.9 ±1.30	32.0
The Sound - North B	55°59'	12°42'	0	Nov 1979	4.8 ±0.74	25.0
- " - - " -	- " -	- " -	25	- " -	2.2 ±0.37	32.0
Barsebäck	38		0	Dec 1979	5.9 ±0.37	21.6
- " -	"		10	- " -	8.5 ±0.74	26.3
Ringhals	2		0	Nov 1979	3.3 ±0.74	23.0
- " -	"		24	- " -	1.85 ±0.35	35.6
Ringhals	57°14'	11°53'07	0	- " -	4.8 ±0.00	24.[illegible]
- " -	- " -	- " -	65	- " -	2.0 ±0.56	36.2
Hesselø	56°10'	11°47'	0	June 1979	5.6 ±0.00	18.1
- " -	- " -	- " -	24	- " -	1.48 ±0.00	34.2
Dybe rende	57°49.9'	11°17.5'	0.5	Aug 1979	2.2 ±0.00	32.1
Hirtshals	57°34.5'	9°42'	0.5	- " -	2.0 ±0.18	32.9
Hanstholm	57°07'	8°27'	0.5	- " -	2.4 ±0.18	32.9
Lyngvig	56°14.4'	7°58'	0.5	- " -	2.8 ±0.18	32.8
Horn rev	55°40'	7°35.4'	0.5	- " -	2.8 ±0.18	33.4
Rømø	55°06.3'	8°16.3'	0.5	- " -	2.6 ±0.00	30.7
The North Sea	57°45'	5°30'	0	June 1979	2.8 ±0.56	30.7
Skagerak	57°17'	9°03'	0	- " -	2.8 ±0.18	30.8
The North Sea	55°59'	7°52'	0	May 1979	3.0 ±0.00	32.8
- " -	55°48'	4°30'	0	June 1979	1.48 ±0.00	35.6
Skagerak	57°41'	10°10'	0	Nov 1979	4.6 ±1.30	26.0
The North Sea	55°17'6	7°07'5	0	Jan 1980	3.1 ±0.56	35.7
Around the Zealand				1971	9.2	

*Triple determinations.

The error term is 1 S.E. of the mean of double determinations.

Table 7.3.5. Tritium in sea water collected in 1980

Location	Position or station number N	E	Depth in m	Date	kBq ^{3}H m^{-3} ±1 S.E.	Salinity o/oo
Kullen	56°15'	12°25'	0	December	7.8±0.37	21.9
- " -	- " -	- " -	22	- " -	5.0±0.56	24.1
Hessele	56°10'	11°47'	0	November	7.4±0.37	24.3
- " -	- " -	- " -	25	- " -	4.6±1.30	33.0
Kattegat SW	56°07'	11°10'	0	July	9.2±1.11	14.4
- " -	- " -	- " -	39	- " -	3.7±0.37	28.4
- " -	- " -	- " -	0	November	7.6±0.56	23.9
- " -	- " -	- " -	33	- " -	6.1±0.18	32.1
Asnæs rev	55°38'	10°47'	0	July	9.4±0.56	12.7
- " -	- " -	- " -	39	- " -	3.3±0.00	30.9
- " -	- " -	- " -	0	November	8.1±1.48	22.1
- " -	- " -	- " -	35	- " -	5.7±0.18	30.7
Halskov rev	55°23'	11°03'	0	August	9.2±0.74	10.8
- " -	- " -	- " -	19	- " -	3.1±0.18	29.2
- " -	- " -	- " -	0	November	7.4±0.74	18.8
- " -	- " -	- " -	20	- " -	6.3±0.37	24.3
Langeland bælt	54°50'	10°50'	0	August	9.1±0.56	9.2
- " -	- " -	- " -	48	- " -	3.3±1.48	29.7
- " -	- " -	- " -	0	December	8.3±0.56	18.4
- " -	- " -	- " -	45	- " -	10.2±0.56	18.6
Femern bælt	54°36'	11°05'	0	August	8.7±0.18	12.0
- " -	- " -	- " -	28	- " -	5.0±0.18	28.8
- " -	- " -	- " -	0	December	8.1±0.00	16.9
- " -	- " -	- " -	20	- " -	8.1±1.11	14.0
Gedser odde	54°28'	11°59'	0	August	9.4±0.56	8.2
- " -	- " -	- " -	18	- " -	3.9±0.56	27.3
- " -	- " -	- " -	0	December	12.0±0.56	13.4
- " -	- " -	- " -	15	- " -	10.9±0.56	14.9
Møen	54°57'	12°41'	0	August	12.6±1.41*	7.9
- " -	- " -	- " -	21	- " -	10.2±0.18	7.8
- " -	- " -	- " -	0	December	10.7±0.37	9.3
- " -	- " -	- " -	21	- " -	9.4±0.18	11.2

Table 7.3.5 continued

Location	Position or station number N	E	Depth in m	Date	kBq ^3H m^{-3} ±1 S.E.	Salinity o/oo
The Sound - South	55°25'	12°39'	0	August	9.4±1.30	11.1
- " -	- " -	- " -	12	- " -	8.5±1.11	12.
- " -	- " -	- " -	0	December	11.7±0.18	11.2
- " -	- " -	- " -	12	- " -	9.4±0.18	11.9
The Sound - North A	55°48'	12°44'	0	August	8.7±1.30	13.6
- " -	- " -	- " -	19	- " -	4.8±1.11	27.2
- " -	- " -	- " -	0	December	6.5±0.92	19.5
- " -	- " -	- " -	20	- " -	7.9±1.30*	22.6
The Sound - North B	55°59'	12°42'	0	August	8.5±0.37	10.7
- " -	- " -	- " -	26	- " -	2.8±0.18	32.9
- " -	- " -	- " -	0	December	5.9±0.37	21.3
- " -	- " -	- " -	25	- " -	5.4±0.18	27.3
Barsebäck	38		0	August	7.4±1.11	13.1
- " -	"		16	- " -	3.0±0.00	31.6
- " -	"		0	November	10.0±0.37	11.2
- " -	"		16	- " -	8.3±0.18	19.2
Ringhals	57°14'	11°53'7	0	July	11.8±0.37	20.8
- " -	- " -	- " -	66	- " -	5.4±1.67	35.3
- " -	- " -	- " -	0	October	4.8±0.00	30.0
- " -	- " -	- " -	65	- " -	2.8±0.18	33.0
- " -	2		0	- " -	6.3±1.15*	18.6
- " -	"		22	- " -	6.1±0.56	29.7
The North Sea	55°57'	3°30'	0	September	2.8±0.56	35.1
- " -	55°55'	5°57'5	0	January 81	5.0±0.56	34.5
- " -	55°13'	8°12'	0	- " -	6.1±0.56	29.5

8. TRANSURANICS IN ENVIRONMENTAL SAMPLES

by Karen Nilsson, Henning Dahlgaard, and Asker Aarkrog

8.1. Materials and methods

The studies have comprised four types of marine samples in sea water, marine sediments, brown algae (Fucoids and Laminaria), and mussels (Mytilus edulis mostly). The samples were collected in Danish waters from Skagen to Bornholm by the research vessel Fyrholm (fig. 8.1).

Sea water samples were measured both as total water and as particulates filtered by a 0.45-μ Gelman Acroflow II filter (500-1000 l h^{-1}). The samples for Pu-Am analysis were 200-1000 l and they were collected by a pump through a rubber tube. The Pu and Am were precipitated with ^{236}Pu and ^{243}Am spikes (kindly provided by Drs. H. Volchoch, EML, and J. Sedlet, ANL) by adding NaOH to the water on board the ship (pH = 10). This method was developed by Dr. Elis Holm, Lund University.

Sediments were collected down to 15-cem depths by the HAPS[18] 135-mm cylindrical stainless steel cover. The samples were divided into 3-cm thick sections before analysis.

Brown algae were collected as fresh growing plants. The total plant was included in the analysis, but epifauna was removed.

Mussels were divided in flesh and shells before the analysis. The bysus threads were removed before the preparation. The samples were analysed for Pu by the method of Talvitie[19,30] and the Am was determined by a method developed by Elis Holm[33].

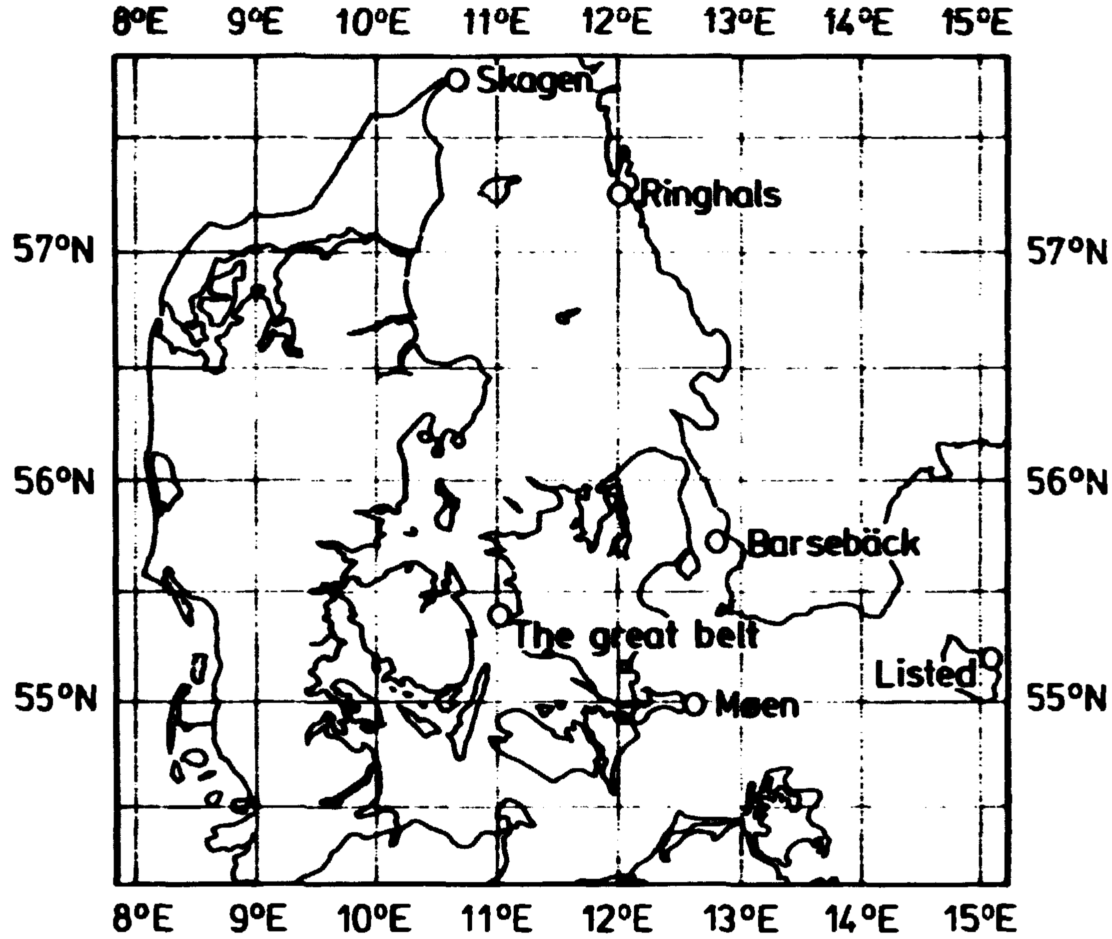


Fig. 8.1. Sampling locations for marine samples in July-August 1980

8.2. Results and discussion

8.2.1. Sea water

Figure 8.2.1 shows that the Pu concentration in sea water increases with increasing salinity in the Danish waters. For comparison, a sample from the Norwegian West Coast (approximately 63° N) and 9 samples from Thule waters (approximately 76° N) (contaminated by fallout only) are plotted on the figure. It appears that these data fitted into the pattern of samples from Danish waters. Kautsky[34] collected 3 sea water surface samples in the Kattegat and two in the Baltic Sea in July 1980. The mean $^{239,240}Pu$ content in these samples was 0.23±0.05 fCi l^{-1} (±1 S.D.) (0.0084 Bq m^{-3}). This was in the same range as our surface water samples collected in July-August 1980.

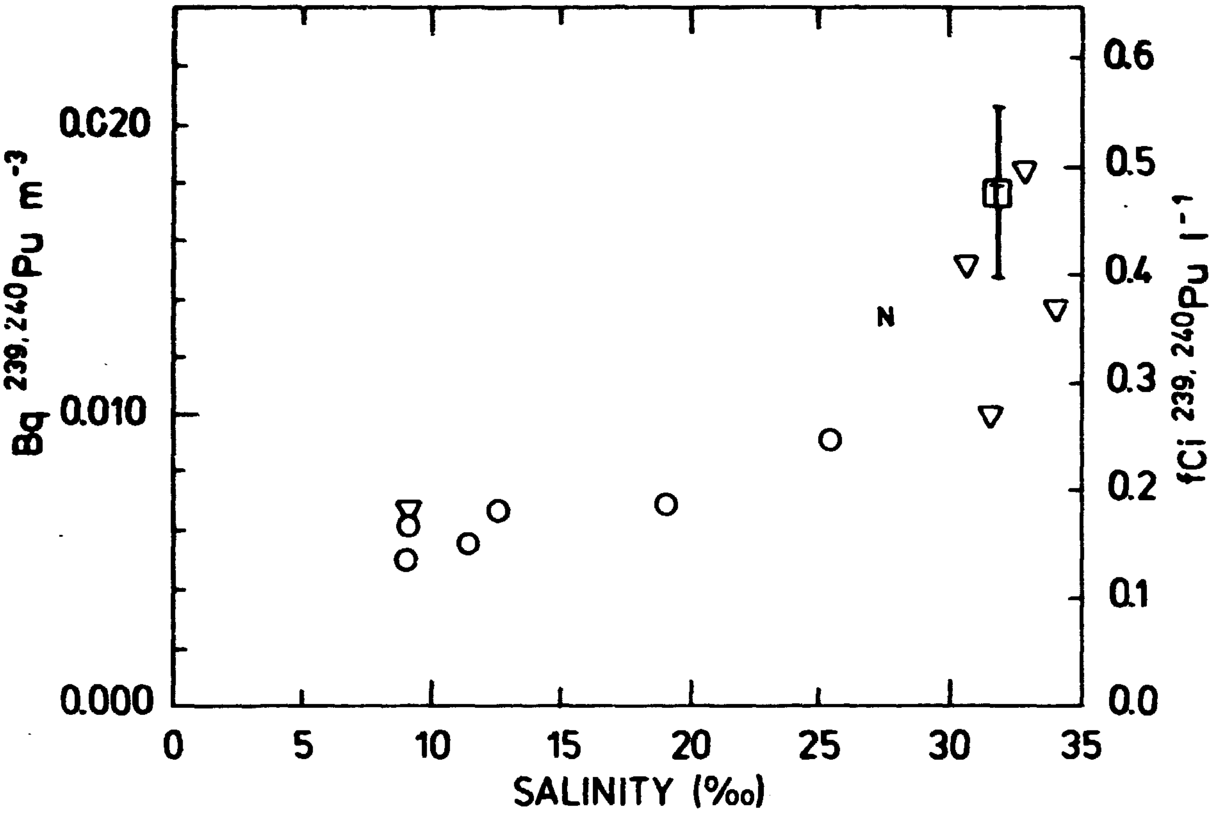


Fig. 8.2.1. Plutonium-239,240 in sea water related to salinity, 1979-1980. o: Danish surface sea water (1980). ∇: Danish bottom sea water (1980). N: Norwegian sea water (1980). T : Thule waters (1979) (±1 S.D., 9 determinations).

The particulate fraction ($\gtrsim$ 0.45 μ) of the Pu activity in the Danish samples were 7±2 (1 S.D.)%. In the Thule samples we found 13±4%. The particulate fraction for Danish inner waters is surprisingly low and may be a result of the filtering method applied.

The mean ratios: $^{241}Am/^{239,240}Pu$ was 0.11±0.03 in Danish waters (1 S.D.; 7 samples); in Thule waters we found 0.18±0.09 (1 S.D., 4 samples). These ratios are lower than that in accumulated fallout (~ 0.3) because Am is more easily removed than Pu from the water column to the sediments.

The source of Pu and Am in Danish waters during 1978-1980 has mainly been global fallout. There may have been contributions from Windscale, too, but this could not be confirmed by our data. Kautsky[34)] has, however, shown an increase in Pu concentrations in the Kattegat in March 1979 which probably was due to Windscale.

Table 8.2.1. Plutonium and Americium in sea water collected in Danish waters in July-August 1980

Location	Sample	Salinity in o/oo	Date	$^{239,240}Pu$		^{241}Am	
				Bq m^{-3}	fCi l^{-1}	Bq m^{-3}	fCi l^{-1}
Skagen	100 l surface water	25.3	July 22	0.0094	0.25	0.002	0.04
- " -	100 l bottom (19 m) water	32.8	- " -	0.019	0.50	0.001	0.03
- " -	[illegible]605 l surface 0.45 μ particulates	25.3	- " -	0.00065	0.018	-	-
The Great Belt	[illegible] l surface water	11.4	Aug 2	0.0055	0.15	-	-
- " -	[illegible] l bottom (19 m) water	30.3	- " -	0.015	0.41	-	-
- " -	719 l surface 0.45 μ particulates	11.4	- " -	0.00044	0.012	-	-
Ringhals 2	200 l surface water	[illegible]5.6	July 16	0.0070	0.19	0.0008	0.02
- " -	10[illegible] l bottom (1[illegible] m) water	34.0	- " -	0.0136	0.37	0.0016	0.04
- " -	1030 l surface 0.45 μ particulates	19.0	- " -	0.00053	0.014	-	-
Barsebäck	1[illegible] l surface water	12.7	Aug 8	0.0069	0.18	-	-
- " -	100 l bottom (16 m) water	31.6	- " -	0.010	0.27	0.0012	0.03
Møen	186 l surface water	8.8	Aug 5	0.0061	0.17	-	-
- " -	100 l bottom (19 m) water	8.8	- " -	0.0065	0.18	-	-
- " -	570 l surface 0.45 μ particulates	8.8	- " -	0.00057	0.015	-	-
Bornholm, Listed	100 l surface water	8.8	Aug 19	0.0053	0.14	-	-
- " -	1000 l surface 0.45 μ particulates	8.8	- " -	0.00017	0.0046	-	-
Mean surface water ±1 S.D.				0.0067±0.002	0.18±0.04	0.0014±0.0009	0.03±0.01
Mean bottom water ±1 S.D. (except Møen)				0.014±0.004	0.39±0.10	0.0013±0.0003	0.03±0.006
Mean particulates ±1 S.D.				0.00047±0.0002	0.013±0.005		

8.2.2. Sediments

In 1980 sediments were collected along with the sea water samples shown above. The mean deposition (0-12 cm) at Ringhals, Barsebäck, and the Great Belt was 56±7 Bq $^{239,240}Pu$ m^{-2} (±1 S.D.) (or 1.5±0.2 nCi m^{-2}). The mean ratio: $^{238}Pu/^{239,240}Pu$ was 0.04±0.015 and the mean ratio: $^{241}Am/^{239,240}Pu$ was 0.35±0.06. These observations are similar to those in the previous period 1975-1979[1].

The mean concentration ratios between 0-3 cm-sediments (Bq kg^{-1} dry weight) and bottom sea water (Bq l^{-1}) were $1 \cdot 10^5$ for $^{239,240}Pu$ and $3 \cdot 10^5$ for ^{241}Am. Similar ratios were found in Thule in 1979. The higher concentration ratio between sediments and sea water for Am than for Pu agrees with the lower solubility of Am in sea water.

Table 8.2.2. Plutonium and Americium in sediments collected in inner Danish waters in July-August 1980

Location & date	Section in cm	$^{239,240}Pu$		$^{238}Pu/^{239,240}Pu$	$^{241}Am/^{239,240}Pu$
		Bq kg^{-1}	Bq m^{-2}		
Ringhals 2	0-3	0.63	13.5	0.071	0.31
(Fig. 3.2.1.2)	3-6	0.55	18.2	0.053	-
July 16	6-9	0.40	14.0	0.03	-
	9-12	0.065	2.4	-	-
Barsebäck 38	0-3	2.09	21.5	0.051	0.27
(Fig. 3.2.1.1)	3-6	2.29	26.9	0.034	0.43
Aug 8	6-9	0.05	0.5	-	-
	9-12	0.65	8.0	0.027	-
The Great Belt	0-3	1.40±0.08	17.8	0.034±0.003	0.36±0.03
55°23'N, 11°03'E	3-6	1.49±0.11	29.3	0.033±0.005	0.36±0.02
Aug 2	6-9	0.72±0.01	14.5	0.024±0.003	0.38
	9-12	0.053±0.002	1.1	-	-
Møen 54°57'N, 12°41'E Aug 5	0-5	0.12	10.3	-	-

The error terms are 1 S.E. of the mean of double determinations.

8.2.3. Sea plants

Sea plants were collected at the same locations as sea water (cf. fig. 8.1). Figure 8.2.3 indicates that the plutonium concentrations in sea plants were lower in 1980 than in 1979, which was contrary to the observation made for ^{137}Cs (cf. 5.11.2). The figure further shows that there was no significant difference in Pu concentrations in Fucoids collected in "low"- and "high"-

salinity Danish waters. Within the year the Pu levels showed variations similar to those observed between years. The reasons for these variations may be explained by the varying growth rate of the sea plants.

Table 8.2.3. Plutonium 239,240 in fucoids and laminaria collected in July-August 1980 in Danish waters

Location and date	Species	Bq kg^{-1} wet	Bq kg^{-1} dry
Skagen July 22	Laminaria	0.014	0.073
- " -	Fucus vesiculosus	0.005	0.031
The Great Belt Aug 2	Fucus vesiculosus	0.013	0.057
Barsebäck Aug 10	Fucus vesiculosus	0.002	0.039
Rødvig-Korsnæb Aug 6	Fucus vesiculosus	0.006	0.033
Listed, Bornholm Aug 19	Fucus vesiculosus	0.006	0.034
Mean ±1 S.D.		0.0077±0.0048	0.045±0.017
Mean		0.21 pCi kg^{-1}	1.20 pCi kg^{-1}

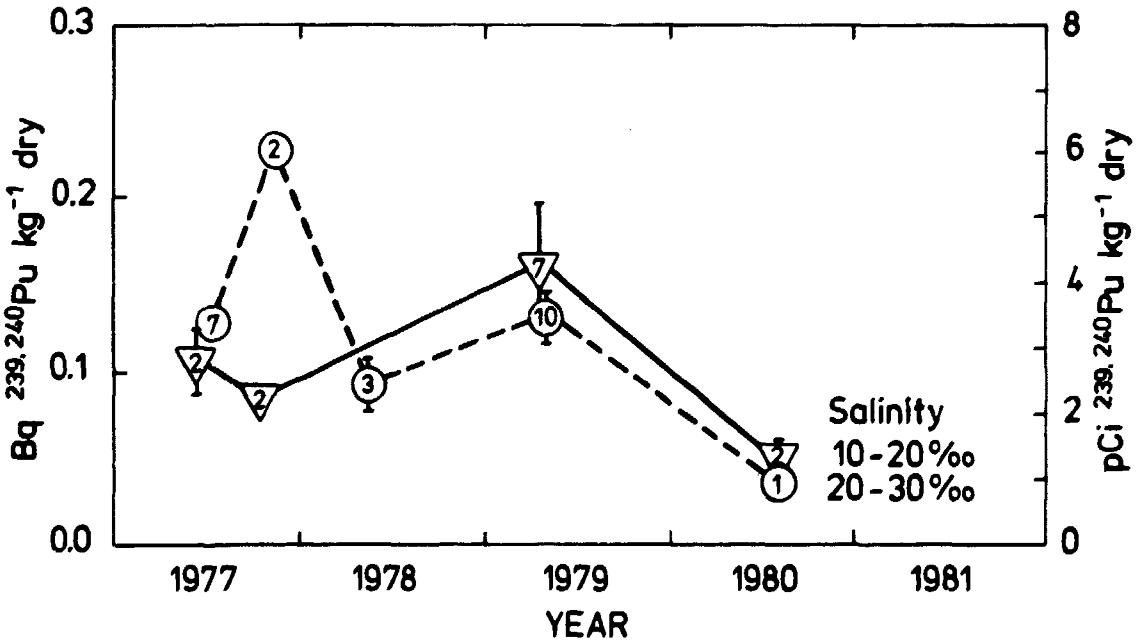


Fig. 8.2.3. Plutonium-239,240 kg^{-1} dry weight fucoids collected in Danish waters 1977-1980. (Mean values ±1 S.E.) (number of samples indicated).

The concentration ratio between brown algae (Bq kg^{-1} dry weight) and surface sea water (Bq l^{-1}) was $(7\pm0.9)\cdot10^3$ (±1 S.E., 5 determinations) for Pu (on a wet weight basis it was $1\cdot10^3$). These ratios are approximately 3 times lower than those observed in Thule (cf. Risø-R-423[35]) but the difference is hardly significant.

Earlier measurements of Am in sea plants[1,35] have shown that the concentration ratio between brown algae and sea water is the same as that observed for Pu.

8.2.4. Mussels

The concentration ratio for plutonium between Mussel flesh (Bq kg^{-1} dry weight) and surface sea water (Bq l^{-1}) was estimated at $(6\pm1.2)\cdot10^3$ (±1 S.E., 5 determinations) (on a fresh weight basis: $6\cdot10^2$); the mean ratio of shells/flesh (dry weight) was 0.31±0.07

Table 8.2.4. Plutonium in mussels collected in Danish waters in July-August 1980

Location and date	Sample	Bq kg^{-1} fresh w.	Bq kg^{-1} dry w.
Skagen July 22	Mytilus edulis flesh	0.0025	0.019
The Great Belt Aug 2	Mytilus edulis flesh	0.0041	0.033
	shell		0.013
Ringhals July 16	Cyrina islandica flesh	0.015	0.079
	shell		0.026
Barsebäck Aug 12	Mytilus edulis flesh	0.0019	0.040
Dragør, the Sound Aug 10	Mytilus edulis flesh	0.0069	0.060
	shell		0.014
Korsnæb, Rødvig Aug 6	Mytilus edulis flesh	0.0051	0.048
Mean (Mytilus edulis flesh) ±1 S.D.		0.0041±0.0020	0.040±0.015
Mean (Mytilus edulis flesh)		0.11 pCi kg^{-1}	1.08 pCi kg^{-1}

(1 S.D.). On a dry weight basis mussels thus showed a concentration ratio similar to that of Fucus; but on a fresh weight basis Fucus concentrated Pu more easily than Mutilus by a factor of approximately two. As for Fucus we found no strong indication of any relationship between salinity and Pu-concentration in mussels.

9. MEASUREMENTS OF BACKGROUND RADIATION IN 1980

by L. Bøtter-Jensen and S.P. Nielsen

9.1. Instrumentation

Measurements of the background radiation were made with thermoluminescence dosimeters (TLD's), a mobile Ge(Li) spectrometer system[24], a high-pressure ionization chamber (Reuter-Stokes RSS-111), and a NaI(Tl) detector.

9.2. State experimental farms

The State experimental farms are situated as shown in fig. 4.2. The results of the TLD measurements are shown in Table 9.2.1. The results of the NaI(Tl) detector measurements are shown in Table 9.2.2.

Table 9.2.1. TLD-measurements of the background radiation (μR h^{-1}) at the State experimental farms in 1979/80

	Winter 1979/80	Summer 1980	Mean
Tylstrup	7.3	7.5	7.4
Borris	6.6	6.5	6.6
Ødum	7.6	7.9	7.8
Askov	7.2	7.3	7.3
St. Jyndevad	6.4	6.4	6.4
Blangstedgård	7.7	7.4	7.7
Tystofte	8.4	8.4	8.4
Abed	8.4	-	8.4
Mean	7.5	7.5	7.5

Table 9.2.2. Terrestrial exposure rates at the State experimental farms measured with the NaI(Tl) detector in 1980 ($\mu R\ h^{-1}$)

Location	June	Sep	Dec	Mean
Tylstrup	3.7	3.0	(3.1)	3.3
Borris	3.5	2.9	(3.0)	3.1
Ødum	5.0	4.4	(4.5)	4.6
Askov	4.1	3.4	3.2	3.6
St. Jyndevad	2.2	1.6	1.8	1.9
Blangstedgaard	4.6	4.0	3.8	4.1
Ledreborg	5.2	4.8	(4.8)	4.9
Tystofte	4.9	3.8	(4.1)	4.3
Abed	5.2	4.8	5.2	5.1
Tornbygård	5.9	(5.3)	(5.3)	5.5
Mean	4.4	3.8	3.9	4.0

Figures in brackets calculated from VAR2[12].

The γ-background measured with the NaI(Tl) detector in four groups of sampling stations is shown in fig. 9.2.1 from 1962 to 1980. The change of levels in 1977 is due to a modification of the instrument and of the calculational procedure[31].

The results of ionization chamber measurements are shown in Table 9.2.3. The results of Ge(Li) spectrometer measurements are shown in Tables 9.2.4 and 9.2.5.

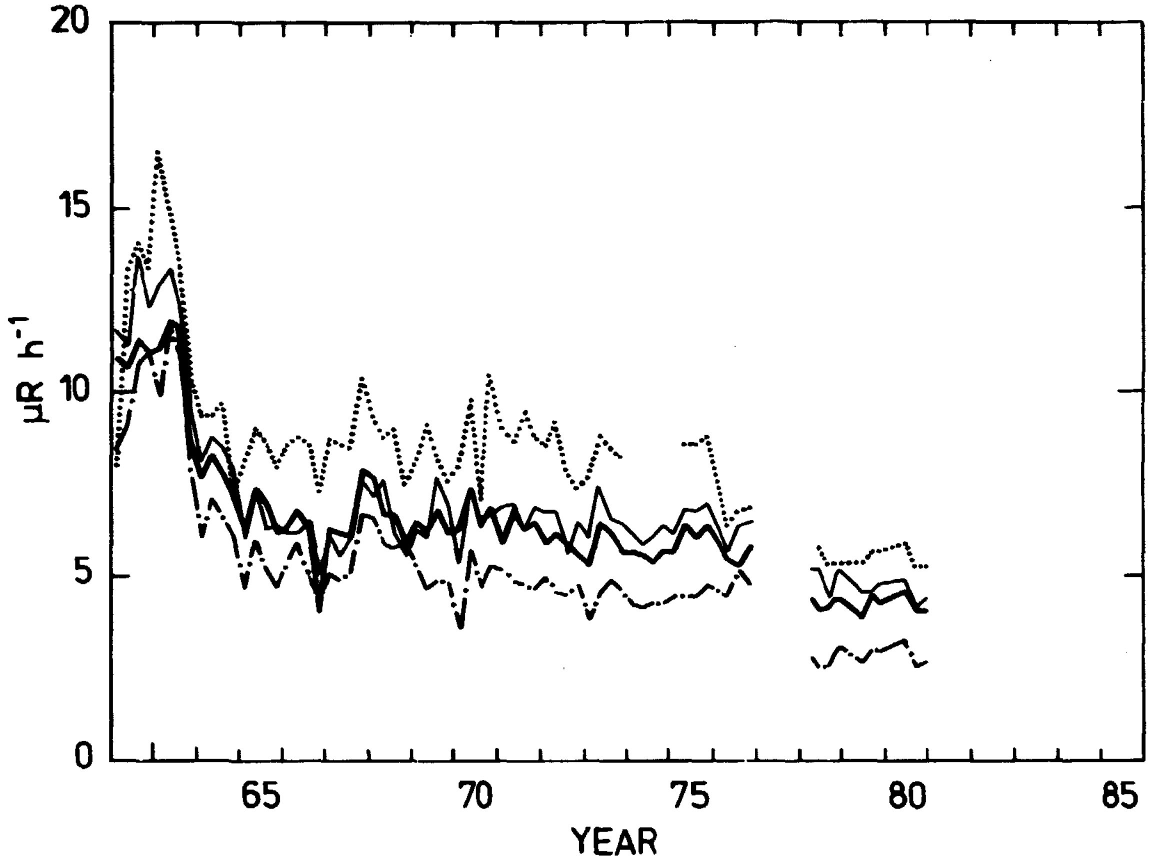


Fig. 9.2.1. Terrestrial exposure rates at the State experimental farms in 1962-1976 and 1978-1980 measured with the NaI(Tl) detector (μR h^{-1}).

..... Åkirkeby/Tornbygård

—— Abed, Blangstedgård, Tystofte

—— Virumgård/Ledreborg, Ødum, Tylstrup

—·— Jyndevad, Askov, Studsgård/Borris

Table 9.2.3. Ionization chamber measurements of the background radiation at the State experimental farms in 1980 (μR h^{-1})

Location	September
Askov	6.9
St. Jyndevad	5.8
Blangstedgård	8.3
Ledreborg	8.7
Abed	8.6
Tornbygård	9.2
Mean	7.9

Table 9.2.4. Terrestrial exposure rates at the State experimental farms estimated from field spectroscopic measurements made in September 1980 ($\mu R\ h^{-1}$)

Location	^{40}K	^{226}Ra	^{232}Th	^{137}Cs	Total
Askov	1.3	0.5	0.6	0.1	2.5
St. Jyndevad	1.0	0.3	0.3	0.2	1.8
Blangstedgård	2.1	0.9	1.3	0.1	4.4
Ledreborg	2.3	0.9	1.5	0.1	4.8
Abed	2.1	1.1	1.2	0.1	4.4
Tornbygård	2.7	0.8	1.4	0.1	4.9
Mean	1.9	0.7	1.1	0.1	3.8

Table 9.2.5. Radionuclides in the soil at the State experimental farms estimated from field spectroscopic measurements made in September 1980. (Unit: $Bq\ kg^{-1}$)

Location	^{40}K	^{226}Ra	^{232}Th	^{137}Cs
Askov	250	6.5	8.1	7.8
St. Jyndevad	200	5.6	4.4	11.1
Blangstedgård	420	17.8	17.8	5.6
Ledreborg	470	17.0	20.4	5.2
Abed	422	20.4	15.9	5.6
Tornbygård	540	15.9	18.1	2.6
Mean	380	14.4	14.1	6.3

9.3. Risø environment

The five zones around Risø are located as shown in fig. 9.3.1. The results of the TLD measurements are shown in Table 9.3.1, and the results of the NaI(Tl) detector measurements are shown in Table 9.3.2.

Table 9.3.1. TLD-measurements of the background radiation (μR h^{-1}) in five zones (I-V) around Risø in 1979/80

Risø zone	Location	Winter 1979/80	Summer 1980	Mean
I	1	8.8	8.2	8.5
"	2	8.9	8.7	8.8
"	3	23.0	21.7	22.4
"	4	9.6	9.0	9.3
"	5	14.9	16.7	15.8
Mean		13.0	12.9	13.0
II	1	8.2	8.2	8.2
"	2	8.6	8.5	8.6
"	3	7.8	7.6	7.7
"	4	8.9	8.4	8.7
Mean		8.4	8.2	8.3
III	1	8.8	8.6	8.7
"	2	7.9	-	7.9
"	3	8.9	8.6	8.8
Mean		8.5	8.6	8.5
IV	1	8.1	7.8	8.0
"	2	8.1	8.5	8.3
"	3	8.6	8.3	8.5
"	4	9.0	8.8	8.9
"	5	6.7	6.4	6.6
"	6	8.1	8.1	8.1
"	7	9.2	9.5	9.4
Mean		8.3	8.2	8.3
V	1	8.2	7.9	8.1
"	2	8.8	8.9	8.9
"	3	8.5	8.4	8.5
"	4	8.4	8.1	8.3
"	5	9.4	9.1	9.3
"	6	8.8	8.7	8.8
"	7	8.7	8.8	8.8
"	8	7.4	7.3	7.4
"	9	9.2	8.7	9.0
"	10	8.1	8.2	8.2
Mean		8.5	8.4	8.5

Table 9.3.2. Terrestrial exposure rates at the Risø zones in 1980 measured with the NaI(Tl) detector ($\mu R\ h^{-1}$)

Risø zone	Location	Feb	May	Aug	Nov
I	1	4.6	4.4	5.3	4.6
"	2	5.7	5.8	7.1	6.7
"	3	74.7	54.4	64.8	58.8
"	4	4.6	6.8	6.2	5.4
"	5	23.5	11.2	33.0	10.8
Mean		22.6	16.5	23.3	17.3
II	1	3.4	5.2	5.2	4.5
"	2	4.7	6.6	6.0	5.2
"	3	3.9	3.9	4.5	3.3
"	4	3.5	5.1	5.3	4.5
Mean		3.9	5.2	5.3	4.4
III	1		6.6	6.0	6.1
"	2		5.2	5.6	4.7
"	3		4.8	5.4	4.4
Mean			5.5	5.7	5.1
IV	1		5.0		4.0
"	2		5.1		4.8
"	3		5.2		4.7
"	4		4.5		4.2
"	5		3.4		3.4
"	6		4.0		4.0
"	7		3.9		4.3
Mean			4.4		4.2
V	1		5.5		4.3
"	2		5.6		5.4
"	3		5.9		4.9
"	4		5.0		4.3
"	5		4.7		4.4
"	6		5.0		4.7
"	7		5.2		4.8
"	8		4.4		4.2
"	9		4.9		4.7
"	10		3.9		4.1
Mean			5.0		4.6

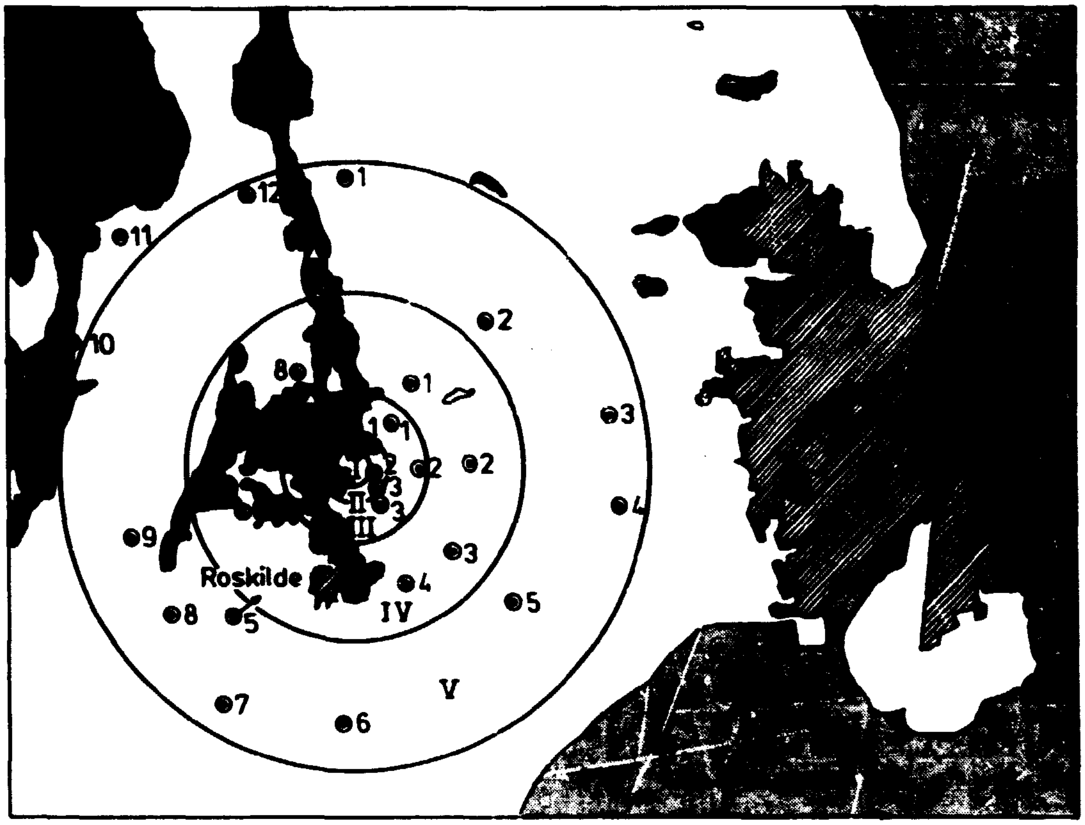


Fig. 9.3.1. The environment of Risø. Locations for measurements of the background radiation.

9.4. Gylling Næs environment

The Gylling Næs environment (a potential nuclear power plant site) is routinely monitored with TLD's, and the results from three zones around the site are given in Table 9.4.1. The locations are shown in fig. 9.4.1.

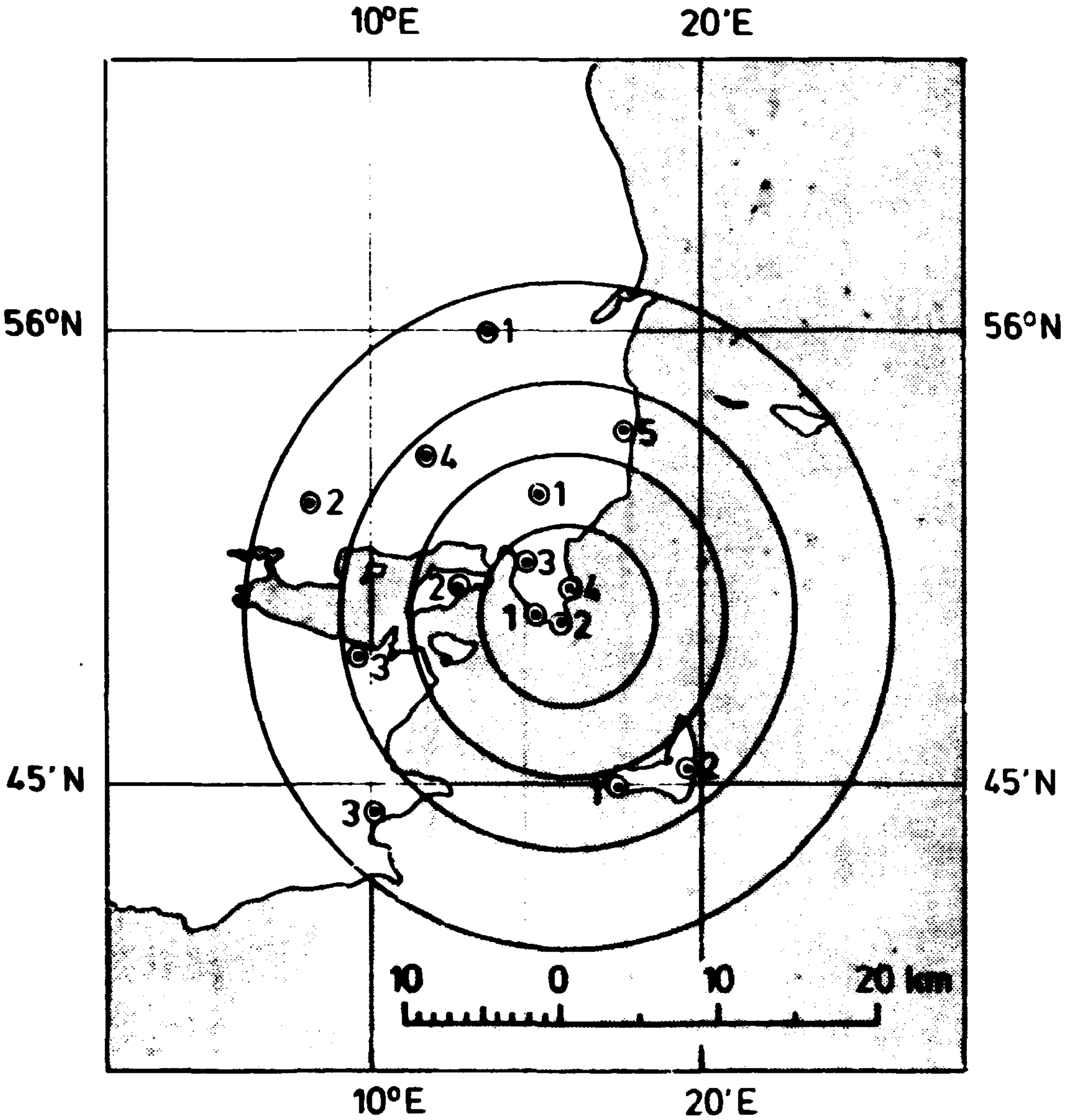


Fig. 9.4.1. The environment of Gylling Næs. Locations for measurements of the background radiation.

Table 9.4.1. TLD-measurements of the background radiation in four zones (I-IV) around the Gyllingnæs site in 1979/80

Gyllingnæs zone	Location	Winter 1979/80
I	1	7.3
"	2	7.6
"	3	8.1
"	4	7.6
Mean		7.7
II	1	8.3
"	2	8.3
Mean		8.3
III	1	7.3
"	2	7.6
"	3	7.9
"	4	-
"	5	8.0
Mean		7.7
IV	1	8.0
"	2	8.1
"	3	7.7
Mean		7.9

9.5. Great Belt and Langeland Belt areas

Locations on both shores of the Great Belt and the Langeland Bel (an international shipping route) are likewise routinely monitored with TLD's; the results and locations are shown in Table 9.5.1 and fig. 9.5.1, respectively.

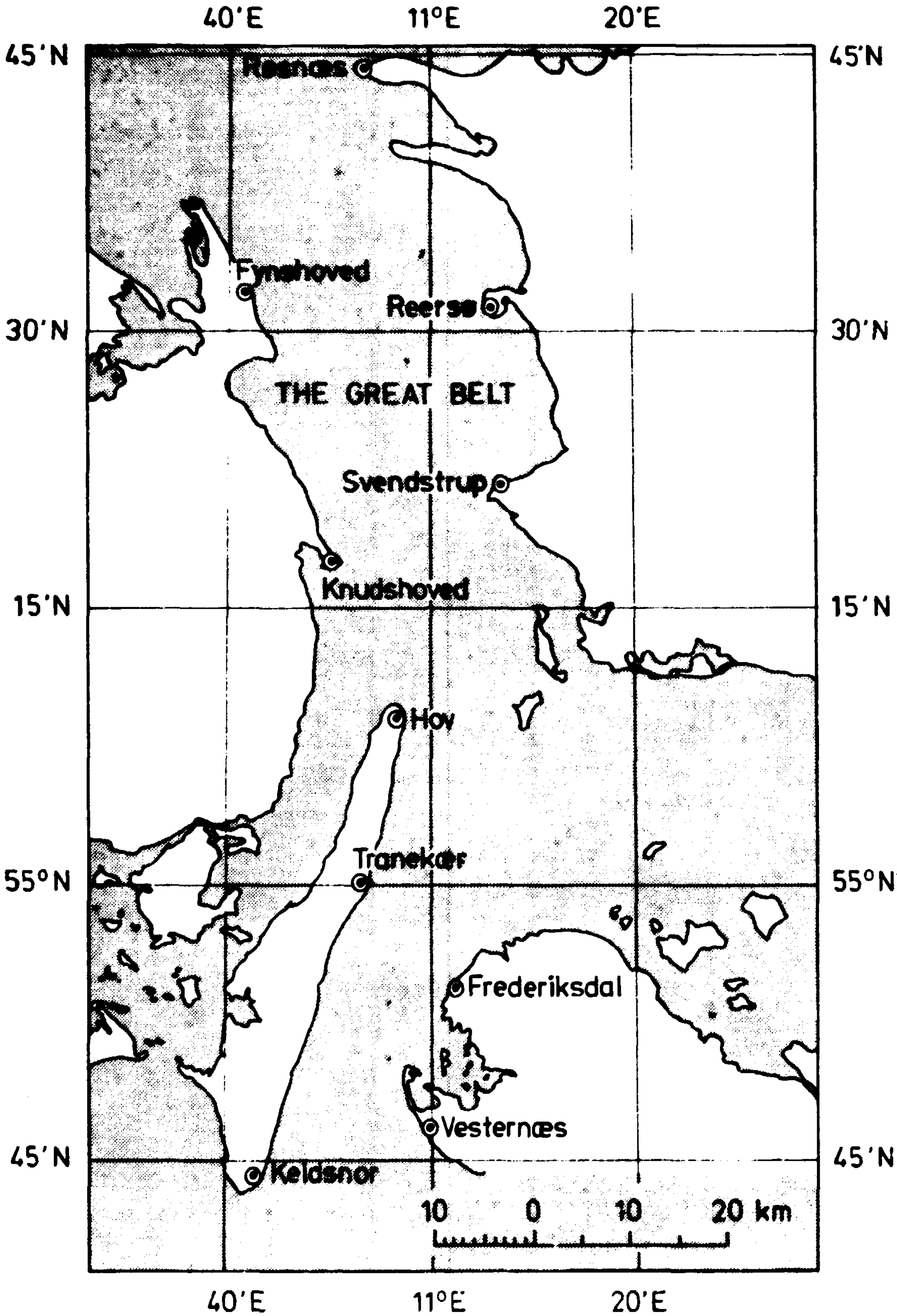


Fig. 9.5.1. The coasts of the Great Belt. Locations for measurements of the background radiation.

Table 9.5.1. TLD-measurements of the background radiation ($\mu R\ h^{-1}$) along the coasts of the Great Belt and Langeland Belt in 1979/80

Location	Winter 1979/80	Summer 1980	Mean
Røsnæs	7.4	7.3	7.4
Reersø	8.5	8.4	8.5
Svendstrup	7.6	7.5	7.6
Frederiksdal	8.7	8.6	8.7
Vesternæs	8.4	8.4	8.4
Kelds Nor	9.3	9.1	9.2
Tranekær	8.6	8.5	8.6
Hov	7.2	7.4	7.3
Fyns Hoved	7.8	8.0	7.9
Knuds Hoved	8.1	8.3	8.2
Mean	8.2	8.2	8.2

9.6. The Baltic island, Bornholm

Locations on the island of Bornholm have been monitored with TLD's in the period November 1979-June 1980. The results and locations are shown in Table 9.6.1 and fig. 9.6.1, respectively.

Table 9.6.1. TLD-measurements of the background radiation on the island Bornholm in 1979/80

Location	Nov 1979-June 1980
1	9.1
2	7.4
3	8.7
4	14.3
Mean	9.9

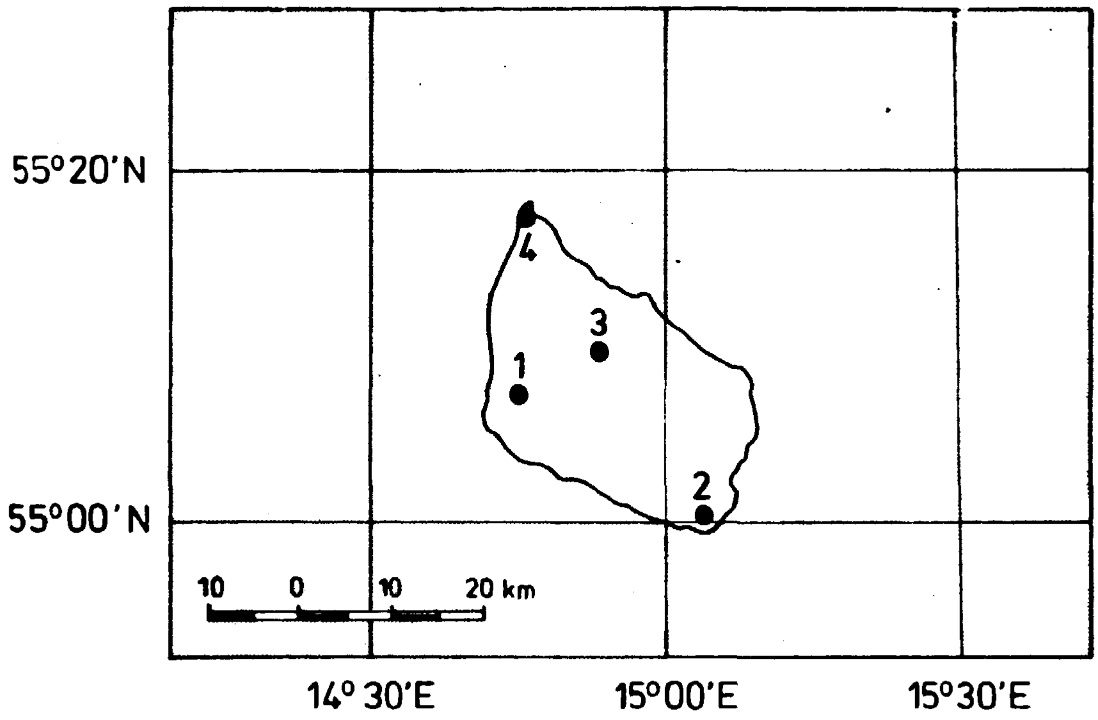


Fig. 9.6.1. Locations for measurements on Bornholm.

9.7. Discussion

The reported results are in reasonable agreement with those obtained in 1979.

10. CONCLUSION

10.1. Environmental monitoring at Risø, Barsebäck and Ringhals

No radioactive contamination of the environment originating from the operation of the research establishment was ascertained outside Risø in 1980.

Benthic brown algae, mussels and fish collected at the Swedish nuclear plants at Barsebäck and Ringhals were analysed for radioactive pollution. Transfer factors from releases of various radionuclides to *Fucus* were calculated. The radioactive contamination of the marine environment due to the operation of the Swedish nuclear power plants resulted into doses of less than 5 μSv per year to any individual eating 20 kg mussel and 100 kg fish per year.

10.2. Nuclear-weapon debris in the abiotic environment

The mean content of ^{90}Sr in air collected in 1980 was 9.9 μBq m^{-3} (0.27 fCi ^{90}Sr m^{-3}), i.e. approximately 0.7 times the 1979 level. The average fallout at the State experimental farms in 1980 was 4.3 Bq ^{90}Sr m^{-2} (0.12 mCi ^{90}Sr km^{-2}) or 0.7 times the 1979 figure, and the mean concentration of ^{90}Sr in rain water was 5.6 Bq ^{90}Sr m^{-3} (0.15 pCi ^{90}Sr l^{-1}).

By the end of 1980 the accumulated fallout was approximately 1750 Bq ^{90}Sr m^{-2} (47 mCi ^{90}Sr km^{-2}). The corresponding ^{137}Cs was estimated at 2800 Bq m^{-2}.

In agreement with the greater precipitation in that part of the country, fallout levels in Jutland were 25-50% higher than levels found in eastern Denmark.

The median level of ^{90}Sr in Danish ground water was 0.14 Bq m^{-3} (4 fCi ^{90}Sr l^{-1}). Lake water showed a countrywide mean level of 4.9 Bq ^{137}Cs m^{-3} (0.135 pCi ^{137}Cs l^{-1}).

Inner Danish surface waters (salinity 16 o/oo) contained 23 Bq ^{90}Sr m^{-3} (0.6 pCi ^{90}Sr l^{-1}) and 43 Bq ^{137}Cs m^{-3} (1.2 pCi ^{137}Cs l^{-1}).

10.3. Fallout nuclides in the human diet

The mean level of ^{90}Sr in Danish milk was 106 Bq (kg Ca)$^{-1}$ (2.9 S.U.), and the mean content of ^{137}Cs was approximately 111 Bq m^{-3} (3.0 pCi ^{137}Cs l^{-1}).

The 1980 ^{90}Sr and ^{137}Cs levels were 1.0 and 0.6 times respectively the levels found in milk produced in 1979.

The ^{90}Sr mean content in grain from the 1980 harvest was 0.84 Bq kg^{-1} (23 pCi ^{90}Sr kg^{-1}). The ^{137}Cs mean content in grain was 0.28 Bq kg^{-1} (7.5 pCi ^{137}Cs kg^{-1}). The ^{90}Sr level in grain from the 1980 harvest was equal to the level found in the 1979 harvest, and ^{137}Cs was 0.75 times the 1979 level.

The mean contents of ^{90}Sr and ^{137}Cs in Danish vegetables collected in 1980 were 0.34 Bq ^{90}Sr kg^{-1} (9.2 pCi kg^{-1}) and 0.084 Bq ^{137}Cs kg^{-1} (23 pCi kg^{-1}), respectively, and in fruit 0.044 Bq ^{90}Sr kg^{-1} (1.2 pCi kg^{-1}) and 0.045 Bq ^{137}Cs kg^{-1} (1.2 pCi kg^{-1}); potatoes contained 0.083 Bq ^{90}Sr kg^{-1} (2.2 pCi kg^{-1}) and 0.077 Bq ^{137}Cs kg^{-1} (2.1 pCi kg^{-1}).

The mean levels of ^{90}Sr and ^{137}Cs in total-diet samples collected in 1980 were 157 Bq ^{90}Sr (kg Ca)$^{-1}$ (4.2 S.U.) and 91 Bq ^{137}Cs (kg K)$^{-1}$ (2.46 M.U.), respectively. From analyses of the individual diet components, the ^{90}Sr level in the Danish average diet was estimated to be 142 Bq ^{90}Sr (kg Ca)$^{-1}$ (3.8 S.U.) and the ^{137}Cs level to be 104 Bq ^{137}Cs (kg K)$^{-1}$ (2.8 M.U.). The levels of ^{137}Cs in the Danish total diet consumed in 1980 were 25% lower than the levels observed in 1979, while the ^{90}Sr content was nearly unchanged.

Grain products contributed 33% and milk products 35% to the total ^{90}Sr intake; 14% of the ^{137}Cs in the diet originated from grain products, 22% from meat, and 13% from milk products. Fish contributed with 35% to the ^{137}Cs diet intake, of this 90% were estimated to be due to radiocesium from Windscale.

Both ^{90}Sr and ^{137}Cs diet levels were on the average higher in Jutland than in eastern Denmark.

10.4. Strontium-90 and Cesium-137 in humans

The ^{90}Sr mean content in human bone (vertebrae) collected in 1980 was about 30 Bq (kg Ca)$^{-1}$ (1.1 S.U.).

Whole-body measurements of ^{137}Cs have been suspended due to the low ^{137}Cs concentrations in man. The estimated level in 1980 was 190 Bq ^{137}Cs (kg K)$^{-1}$ (5 pCi ^{137}Cs (g K)$^{-1}$).

10.5. Tritium in environmental samples

Tritium levels varied between 4.3 and 113 kBq m^{-3} in rain water and between 0.56 and 11.8 kBq m^{-3} in ground water. The tritium concentration in sea water varied inversely as the salinity, 16 o/oo sea water contained 8.4 kBq m^{-3}.

10.6. Plutonium in environmental samples

Plutonium and americium were determined in sea water, sediments, fucoids and mussels collected at five locations in inner Danish waters. The mean concentrations were: surface sea water 6.7 μBq $^{239,240}Pu$ l^{-1} (0.18 fCi l^{-1}), bottom water: 14 μBq l^{-1} (0.39 fCi l^{-1}) ($^{241}Am/^{239,240}Pu$ = 0.15); the mean deposition in sediments was 56 Bq $^{239,240}Pu$ m^{-2} (1.5 nCi m^{-2}) and the ^{241}Am level was one third of this.

10.7. Background radiation

The average total background exposure rate measured with TLD's at the State experimental farms was 7.5 μR h^{-1}. The average terrestrial background exposure rate measured with a NaI(Tl) detector at the State experimental farms was 4.0 μR h^{-1}. These results are in accordance with those observed in 1979.

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We are specially indebted to the staffs of the eleven State experimental farms at Tylstrup, Ødum, Studsgård, Borris, Askov, St. Jyndevad, Blangstedgård, Tystofte, Ledreborg, Abed, and Åkirkeby, who have continued to supply us with a number of the most important samples dealt with in this report.

Finally, we convey our thanks to M/S "Havørnen" in Hanstholm and M/S "Nordjylland" in Skagen for the sea water samples received from the North Sea.

Appendix A. Calculated fallout in Denmark in 1980

Zone		mm precipitation in 1980	Bq ^{90}Sr m^{-2} in 1980	Accumulated Bq ^{90}Sr m^{-2} by the end of 1980
I:	N. Jutland	912 (970)	4.87	1949
II:	E. Jutland			
III:	W. Jutland			
IV:	S. Jutland			
V:	Funen	779 (697)	3.63	1555
VI:	Zealand			
VII:	Lolland-Falster			
VIII:	Bornholm	779 (812)	4.41	-
Area-weighted mean		809 (830)	4.2	1700

The amounts of precipitation were obtained from ref. 9. The ^{90}Sr deposition was estimated from 4.2 and appendix D.

The precipitations in brackets were the mean of values measured by the Meteorological Institute at the State experimental farms:
Jutland: Tylstrup, Ødum, Studsgård, Askov, St. Jyndevad;
The Islands: Blangstedgård, Tystofte, Ledreborg, Abed;
Bornholm: Åkirkeby.

Appendix B. Statistical information

Zone		Area in km^2 15) 1971	Population in thousands 28) 1976	Annual milk production in mega-kg 14) 1971	Annual wheat production in mega-kg 13) 1972	Annual rye production in mega-kg 13) 1972	Annual potato production in mega-kg 13) 1972	Vegetable area in km^2 13) 1972
I:	N. Jutland	6,171	471	911				
II:	E. Jutland	7,561	881	1,258	145	155	609	14
III:	W. Jutland	12,104	687	926				
IV:	S. Jutland	3,929	245	572				
V:	Funen	3,486	446	393				
VI:	Zealand	7,435	2,165*	395				
VII:	Lolland-Falster	1,795	123	68	448	71	100	73
VIII:	Bornholm	588	47	39				
Total		43,069	5,065	4,562	593	226	709	87

*1,270,000 people were living in Greater Copenhagen and 895,000 in the remaining part of Zealand.

APPENDIX C

The mean ratio between observed and predicted values was 1.22± 0.52 (1 S.D.) for ^{90}Sr and 1.15±0.43 for ^{137}Cs. In general, the prediction models underestimated the levels in 1980.

For the calculation of the ^{137}Cs levels we have assumed the $^{137}Cs/^{90}Sr$ ratio equal to 1.6. This may as is suggested from Tables 4.2.4 and 4.2.5 have overestimated the ^{137}Cs deposition in 1980, on the other hand, it may have underestimated it for the previous years[1].

Appendix C.1. Comparison between observed and predicted ^{90}Sr levels in environmental samples collected in 1980

Sample	Location	Unit	Observed	Predicted	Obs./pred.	Model in reference (21)
Dried milk*	Jutland	Bq ^{90}Sr (kg Ca)$^{-1}$	128	137	0.93	C.3.2.1 No. 1
" "	Islands	- " -	85	65	1.31	- " - No. 3
Rye	Jutland	Bq ^{90}Sr kg^{-1}	1.00	0.55	1.82	C.2.2.1 No. 1
"	Islands	- " -	0.39	0.179	2.18	- " - No. 3
Barley	Jutland	- " -	1.02	0.75	1.36	- " - No. 4
"	Islands	- " -	0.71	0.33	2.15	- " - No. 6
Wheat	Jutland	- " -	1.22	0.74	1.65	- " - No. 8
"	Islands	- " -	0.57	0.33	1.73	- " - No. 10
Oats	Jutland	- " -	1.08	1.54	0.70	- " - No. 12
"	Islands	- " -	0.79	0.73	1.08	- " - No. 13
Rye bread	Denmark	- " -	0.66	0.42	1.57	C.2.3.1 No. 1
White bread	"	- " -	0.159	0.14	1.14	- " - No. 2
Potatoes	Jutland	- " -	0.106	0.112	0.95	C.2.5.1 No. 8
"	Islands	- " -	0.059	0.100	0.59	- " - No. 10
Cabbage	Jutland	- " -	0.60	0.35	1.71	- " - No. 1
"	Islands	- " -	0.30	0.30	1.00	- " - No. 3
Carrot	Jutland	- " -	0.56	0.60	0.93	- " - No. 5
"	Islands	- " -	0.42	0.24	1.77	- " - No. 6
Apples	Denmark	- " -	0.034	0.018	1.89	- " - No. 13
Pork*	"	- " -	0.006	0.029	0.21	C.3.4.1 No. 3
Beef*	"	- " -	0.020	0.039	0.51	- " - No. 1
Eggs	"	- " -	0.014	0.0178	0.79	C.3.6.1 No. 6
Total diet C	"	Bq ^{90}Sr (kg Ca)$^{-1}$	157	170	0.92	C.4.2.1 No. 1
" " P	"	- " -	144	147	0.97	- " - No. 7
Human bone > 29 yr	"	- " -	33	43.7	0.76	C.4.3.1 No. 13
Whole year grass	Islands	- " -	1080	576	1.88	C.2.4.1 No. 1
Fucus vesiculosus	"	- " -	393	497	0.79	C.2.7.1 No. 3
Zostera marina	"	- " -	70	84	0.83	- " - No. 1
Ground water	Denmark	Bq ^{90}Sr m^{-3}	0.44	0.38	1.16	C.1.4.1 No. 1

*May 1980 - April 1981 ("milk year" (21)).

Appendix C.2. Comparison between observed and predicted ^{137}Cs levels in environmental samples collected in 1980

Sample	Location	Unit	Observed	Predicted	Obs./pred.	Model in reference (21)
Dried milk*	Jutland	Bq ^{137}Cs (kg K)$^{-1}$	81	69	1.17	C.3.2.2 No. 1
" "	Islands	- " -	33	40	0.83	- " - No. 3
Rye	Jutland	Bq ^{137}Cs kg^{-1}	0.37	0.44	0.84	C.2.2.4 No. 2
"	Islands	- " -	0.29	0.22	1.33	- " - No. 3
Barley	Jutland	- " -	0.30	0.28	1.09	- " - No. 4
"	Islands	- " -	0.22	0.15	1.50	- " - No. 5
Wheat	Jutland	- " -	0.32	0.30	1.08	- " - No. 6
"	Islands	- " -	0.17	0.13	1.36	- " - No. 7
Oats	Jutland	- " -	0.37	0.24	1.52	- " - No. 8
"	Islands	- " -	0.23	0.14	1.69	- " - No. 9
Rye bread	Denmark	- " -	0.33	0.47	0.70	C.2.3.1 No. 4
White bread	"	- " -	0.100	0.155	0.65	- " - No. 5
Potatoes	Jutland	- " -	0.127	0.153	0.83	C.2.5.3 No. 5
"	Islands	- " -	0.027	0.019	0.70	- " - No. 7
Cabbage	Denmark	- " -	0.134	0.174	0.77	- " - No. 1
Carrot	"	- " -	0.050	0.020	2.50	- " - No. 3
Apples	"	- " -	0.045	0.045	1.00	- " - No. 11
Pork*	"	- " -	0.38	0.30	1.27	C.3.4.2 No. 3
Beef*	"	- " -	0.38	0.26	1.46	- " - No. 1
Eggs	"	- " -	0.028	0.039	0.72	C.3.6.2 No. 6
Total diet C	"	Bq ^{137}Cs (kg K)$^{-1}$	63**	52.5	1.20	C.4.2.2 No. 1
" " P	"	- " -	71.6**	70.9	1.01	- " - No. 6

* (cf. note to Appendix C.1)

**Exclusive contribution of ^{137}Cs from Windscale. (30% Windscale, 70% fallout)

APPENDIX D

$\underline{d_i}$:

Annual fallout rate in mCi ^{90}Sr km^{-2} y^{-1}.

Accumulated fallout by the end of the year (i) assuming effective half-lives of ^{90}Sr of 27.7 y. Unit: mCi ^{90}Sr km^{-2}.

$\underline{d_{i(May-Aug)} \text{ and } d_{i(July-Aug)}}$:

The fallout rates in the periods: May-Aug and July-Aug, respectively. Unit: mCi ^{90}Sr km^{-2} period^{-1}.

The fallout rate (d_i) was based on precipitation data collected for all Denmark in the period 1962-1980 (cf. Table 4.2.1[1]). Before 1962 the levels in the tables were estimated from the HASL data for New York (HASL Appendix 291, 1975)[29] considering that the mean ratio between ^{90}Sr fallout in Denmark and New York was 0.7 in the period 1962-1974.

The $d_{i(May-Aug)}$ and $d_{i(July-Aug)}$ values were also obtained from Table 4.2.1[1] for the period 1962-1980. For the years 1959-1961 the values were calculated from data obtained from ^{90}Sr analysis of air (1959) and precipitation samples (1962 and 1961) collected at Risø. Before 1959, the values were estimated from the corresponding d_i values assuming that the ratios $d_{i(May-Aug)}/d_i$ and $d_{i(July-Aug)}/d_i$ were constant in time and equal to the means found for the period 1962-1974, which were 0.54 (1 S.D.: 0.09) and 0.24 (1 S.D.: 0.06), respectively.

Appendix D. Fallout rates and accumulated fallout (mCi ^{90}Sr km^{-2}) in Denmark 1950-1980

	Denmark		Jutland		Islands	
	di	Ai(27.7)	di	Ai(27.7)	di	Ai(27.7)
1950	0.021	0.020	0.022	0.021	0.020	0.020
1951	0.101	0.118	0.114	0.132	0.088	0.105
1952	0.198	0.309	0.224	0.347	0.172	0.270
1953	0.500	0.789	0.566	0.891	0.434	0.687
1954	1.901	2.623	2.152	2.967	1.650	2.279
1955	2.501	4.997	2.831	5.655	2.171	4.340
1956	3.101	7.898	3.510	8.939	2.692	6.858
1957	3.101	10.728	3.510	12.142	2.692	9.313
1958	4.302	14.658	4.869	16.591	3.734	12.725
1959	6.102	20.247	6.908	22.918	5.297	17.576
1960	1.140	20.859	1.291	23.610	0.990	18.107
1961	1.481	21.787	1.676	24.661	1.285	18.913
1962	7.428	28.493	7.976	31.830	6.880	25.155
1963	16.695	44.071	18.453	49.041	14.937	39.101
1964	10.412	53.136	11.685	59.225	9.139	47.048
1965	3.954	55.679	4.204	61.861	3.704	49.497
1966	2.145	56.395	2.166	62.445	2.124	50.345
1967	1.047	56.023	1.176	62.048	0.918	49.997
1968	1.403	56.006	1.568	62.045	1.237	49.968
1969	1.035	55.632	1.241	61.721	0.829	49.542
1970	1.647	55.863	1.993	62.140	1.301	49.586
1971	1.506	55.951	1.726	62.288	1.286	49.615
1972	0.435	54.993	0.457	61.194	0.413	48.792
1973	0.192	53.821	0.215	59.891	0.168	47.750
1974	0.710	53.183	0.779	59.171	0.643	47.197
1975	0.414	52.272	0.452	58.150	0.376	46.397
1976	0.103	51.082	0.116	56.826	0.090	45.339
1977	0.384	50.204	0.405	55.827	0.362	44.581
1978	0.463	49.426	0.538	54.985	0.388	43.867
1979	0.166	48.379	0.174	53.810	0.156	42.947
1980	0.116	47.307	0.140	52.628	0.095	41.988

Denmark		Jutland		Islands	
$d_{i(May-Aug)}$	$d_{i(July-Aug)}$	$d_{i(May-Aug)}$	$d_{i(July-Aug)}$	$d_{i(May-Aug)}$	$d_{i(July-Aug)}$
0.01	0.01	0.01	0.01	0.01	0.01
0.05	0.02	0.06	0.03	0.05	0.02
0.11	0.05	0.12	0.05	0.09	0.04
0.27	0.12	0.31	0.14	0.23	0.10
1.03	0.46	1.16	0.52	0.89	0.40
1.35	0.60	1.53	0.68	1.17	0.52
1.67	0.74	1.90	0.84	1.45	0.65
1.67	0.74	1.90	0.84	1.45	0.65
2.32	1.03	2.63	1.17	2.02	0.90
2.50	0.68	2.76	0.75	2.24	0.61
0.47	0.31	0.52	0.34	0.42	0.28
0.66	0.47	0.73	0.52	0.59	0.42
4.223	1.857	4.566	2.052	3.880	1.662
9.965	5.629	10.753	5.932	9.177	5.327
6.235	2.568	7.170	2.910	5.299	2.226
2.029	0.850	2.094	0.852	1.964	0.848
1.049	0.418	0.984	0.496	1.114	0.340
0.367	0.141	0.380	0.134	0.354	0.148
0.848	0.426	0.910	0.460	0.786	0.392
0.614	0.276	0.723	0.319	0.505	0.233
0.908	0.547	1.076	0.632	0.740	0.462
0.992	0.405	1.154	0.516	0.830	0.294
0.253	0.084	0.262	0.084	0.244	0.084
0.075	0.033	0.093	0.039	0.057	0.027
0.421	0.190	0.463	0.219	0.378	0.162
0.159	0.075	0.179	0.091	0.157	0.060
0.032	0.010	0.032	0.011	0.032	0.009
0.178	0.107	0.164	0.085	0.190	0.129
0.232	0.096	0.275	0.098	0.188	0.093
0.086	0.030	0.087	0.031	0.084	0.029
0.063	0.027	0.079	0.031	0.047	0.022

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